INSTRUCTION MANUAL

MODELS 416, 417

HIGH SPEED PICOAMMETERS

KEITHLEY INSTRUMENTS

WARRANTY

We warrant each of our products to be free from defects in material and workmanship. Our obligation under this warranty is to repair or replace any instrument or part thereof which, within a year after shipment, proves defective upon examination. We will pay domestic surface freight costs.

To exercise this warranty, call your local field representative or the Cleveland factory, DDD 216-248-0400. You will be given assistance and shipping instructions.

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Keithley Instruments maintains a complete repair service and standards laboratory in Cleveland, and has an authorized field repair facility in Los Angeles and in all countries outside the United States having Keithley field representatives.

To insure prompt repair or recalibration service, please contact your local field representative or the plant directly before returning the instrument.

Estimates for repairs, normal recalibrations, and calibrations traceable to the National Bureau of Standards are available upon request.

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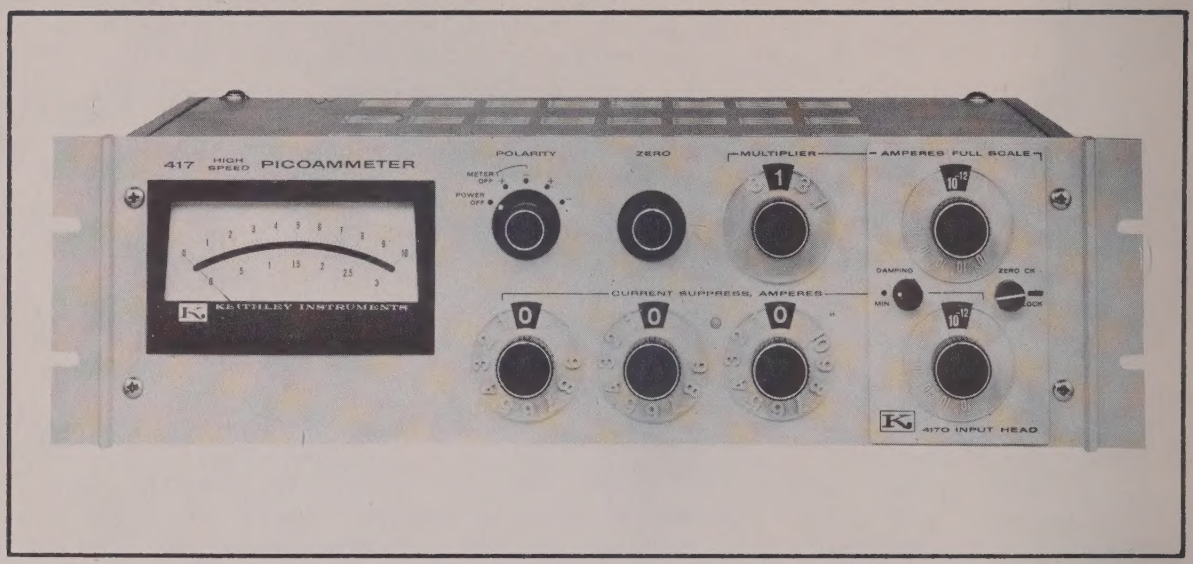


FIGURE 1. Keithley Model 417 High-Speed Picoammeter.

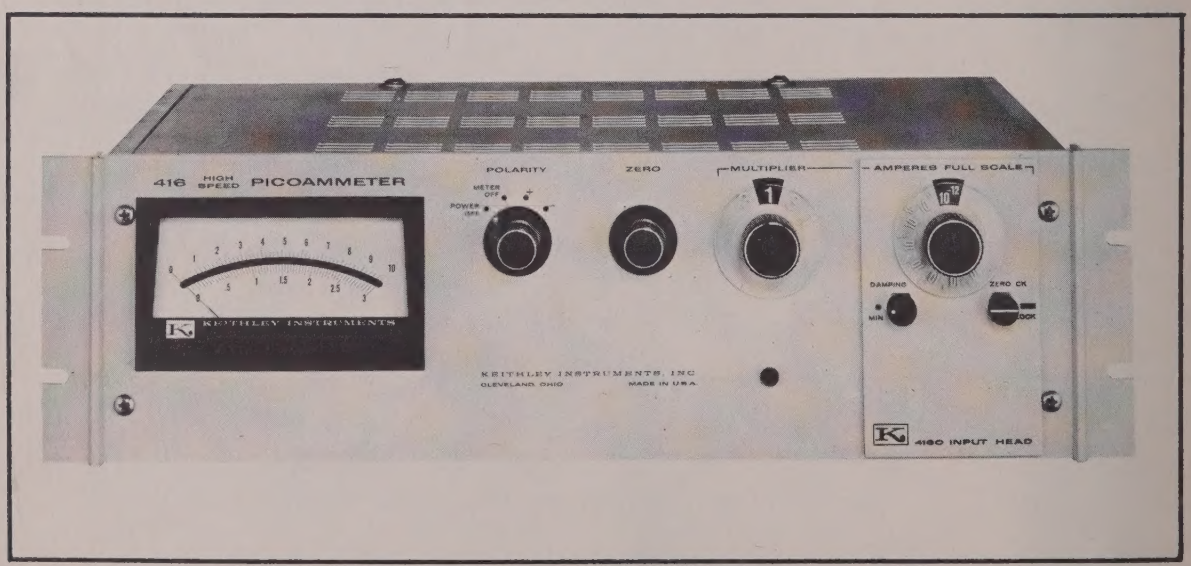


FIGURE 2. Keithley Model 416 High-Speed Picoammeter.

SECTION 1. GENERAL DESCRIPTION

1-1. GENERAL.

a. The Keithley Models 416 and 417 High-Speed Picoammeters measure currents over 18 ranges from 10^{-13} to 3×10^{-5} ampere full scale. The rise time of the instruments is 30 milliseconds on the 10^{-12} ampere range with no external capacitance across the input. Accuracy is ± 2% of full scale from 3×10^{-5} to 10^{-8} ampere, and ± 3% of full scale on the other ranges. Zero drift is less than 1% per eight hours.

b. The Picoammeters use an electrometer tube input with solid-state amplifiers and power supply. The amplifier circuit is completely contained in the Models 4160 and 4170 Input Heads, which can be removed from the main chassis and operated remotely up to distances of 25 feet. The full capabilities of the high-speed circuitry are realized, therefore, by minimizing external capacitance and noise usually introduced by long cable runs to the input.

1-2. FEATURES.

a. Variable damping increases the rise time approximately three seconds to facilitate measurements of steady currents without disturbances due to 60 cps pickup or noise.

b. Three volts at full-scale deflection on all ranges is provided at up to one milliampere to drive chart recorders directly.

c. A zero check switch permits zeroing the meter without disturbing the circuit.

1-3. DIFFERENCES BETWEEN THE MODELS 416 AND 417.

a. The Picoammeter circuits in the two models are the same. The Model 417, however, provides a suppression current at the input up to 1000 times full scale on most ranges. This permits full-scale display of 0.1% variations of a signal or suppression of a steady background signal.

b. The instructions in this Manual are for both models, except those paragraphs concerning the suppression current operation and circuit. These instructions are identified as applying only to the Model 417. Separate schematic diagrams are contained in the Manual for each instrument.

1-4. APPLICATIONS.

a. The Models 416 and 417 are especially useful for high-speed measurements of low-level currents generated by high-impedance sources. Typical examples include photo-multipliers, high-speed mass spectrometers, ion chambers, flame and beta-ray ionization detectors. Other applications include transient current measurements, noise studies and flash filament testing.

b. The damping control permits use in applications where rapid transients are of little interest, as in low-sweep rate mass spectrometry. The variable damping also provides a convenient method of eliminating 60 cps pick-up and external noise from the dc current measurement. The zero drift of less than 1% of full scale per eight hours makes possible measurements of extended duration, such as stability of high-impedance low-level current sources, long-term drift runs, and the studies of noise characteristics of components.

c. The ±3 volt recorder output and the convenience of remote operation facilititate long-term monitoring of nuclear reactors. In these and other remote monitoring applications, response speed is not degenerated by the effects of external capacitance and noise usually introduced by long cable runs. The Models 416 and 417 are also adaptable to automatic reactor control when equipped with the Model 4103 Electronic Trip. One or two Trips may be installed in either instrument.

d. The suppression current feature of the Model 417 permits observations of 0.1% variations of a signal, or suppression of steady background signals, such as dark current in photocells.

1-5. SPECIFICATIONS.

RANGE: 10^{-13} ampere full scale to 3×10^{-5} ampere in eighteen 1x and 3x ranges, positive or negative currents.

ACCURACY: ±2% of full scale on 3×10^{-5} to 10^{-8} ampere ranges; ±3% of full scale on 3×10^{-9} to 10^{-13} ampere ranges.

ZERO DRIFT: Less than 1% of full scale per 8 hours on any range with multiplier set at 1 after a 30-minute warm-up and with source voltages greater than 1 volt. With multiplier settings of 0.3 and 0.1, the drift is increased in proportion to the increase in sensitivity.

ZERO CHECK: Allows zeroing without disturbing the circuit.

GRID CURRENT: Less than 2×10^{-14} ampere.

INPUT VOLTAGE DROP: Less than 1 millivolt for full-scale meter deflection on all ranges when properly zeroed.

EFFECTIVE INPUT RESISTANCE: 100 ohms on 10^{-5} ampere range, increasing to 10,000 megohms on 10^{-13} ampere range in decade steps.

RISE TIME, MAXIMUM: Seconds, from 10% to 90%.

Range, ampere	No External Capacitance	With 50 pf Across Input	With 500 pf Across Input	With 5000 pf Across Input
10^{-13}	0.5	1.0	3.5	18.0
10^{-12}	0.03	0.06	0.4	4.0
10^{-11}	0.005	0.01	0.035	0.4
10^{-10}	0.004	0.004	0.006	0.04
10^{-9}	0.004	0.004	0.004	0.006
10^{-8}	0.004	0.004	0.004	0.004
10^{-7} and above	less than 0.001	less than 0.001	less than 0.001	less than 0.001

NOTE

Rise time may be lengthened by approximately 3 seconds with variable damping control on 3×10^{-8} to 10^{-13} ampere ranges.

CALIBRATED CURRENT SUPPRESSION (MODEL 417 ONLY): Up to 1000 full scale; maximum suppression, 10^{-4} ampere. Suppression current is read directly from 4 in-line dials. Accuracy is $\pm$5% of reading or $\pm$5% of decade setting, whichever is greater; except for the 10^{-12} decade where it degrades to $\pm$10% with multiplier settings between 50 and 100.

RECORDER OUTPUT:

Output: $\pm$3 volts at up to 1 milliampere for full-scale meter deflection. Output polarity is opposite input polarity.

Resistance: Less than 5 ohms.

Noise: Less than 3% rms of full scale on 10^{-13} ampere range at minimum damping, decreasing to 0.3% rms with maximum damping.

CONNECTORS: Input: Teflon-insulated uhf type. Output: Amphenol 80-PC2F. Remote: Cannon DA15S.

POWER: 105-125 or 210-250 volts (switch selected), 50-1000 cps, 15 watts (416), 20 watts (417).

DIMENSIONS, WEIGHT: 5-1/4 inches high x 19 inches wide x 13-1/2 inches deep; net weight, 20 pounds (416), 21 pounds (417).

ACCESSORIES SUPPLIED: Mating input and output connectors.

1-6. ACCESSORIES. The following accessories may be used to increase measurement convenience of both the Model 416 and the Model 417. Refer to Section 2 for operating and installing instructions.

a. Model 4171 Remote Zero Switch enables the Picoammeter to be zeroed from the instrument chassis when the Input Head is remotely located.

b. Model 4172 Remote Input Housing provides a firm mounting base for either the Model 4160 Input Head or the Model 4170 Input Head. Four 1/4-inch diameter mounting holes are on the base flange to attach the Housing to another mounting. The Housing dimensions are 6 inches high x 5-3/8 inches wide x 13 inches deep. Net weight is 4-1/2 pounds.

c. Model 4173 Remote Cable is required to connect the Input Head to the Picoammeter main chassis for remote operations. The cable is not sensitive to normally encountered magnetic and electrostatic fields or movements. The polyvinyl chloride outside jacket will resist most chemicals, solvents and oils. Standard cables available complete with connectors are:

Model Number	Length
4173-10	10 feet
4173-25	25 feet

Lengths up to 500 feet are available on special order. (See paragraph 2-6.)

d. Model 4103 Electronic Trip is a compact, self-contained, transistorized amplifier designed to convert the Model 416 or 417 into a self-contained, automatic control system. The Model 4103 requires only one adjustment, a trip level which can be set by the user. The exposed terminal strip permits the user to make rapid and easy changes in polarity, high or low trip level, and trip level sensitivity. Both the Models 416 and 417 can accommodate one or two Electronic Trips within their chassis. (Refer to Figure 19.)

e. Model 3000 Bench Mounting Kit converts the Picoammeter from a rack-mounted unit to one suitable for bench use. The Kit contains four feet with rubber inserts, a tilt bail and a hooded top cover. As a bench model, the Picoammeter is 5-1/2 inches high x 17-1/2 inches wide x 13-1/2 inches deep.

f. Model 6106 Electrometer Connection Kit contains a group of the most useful leads and adapters for electrometer measurement. See Section 2-11 for complete description.

g. Model 370 Recorder allows convenient and accurate recording with the Picoammeters. The Model 370's input cable has a connector which mates directly with Keithley Picoammeters and electrometers. The Recorder is a chart recorder with 10 chart speeds and 1% linearity.

1-7. EQUIPMENT SHIPPED. The Models 416 and 417 High-Speed Picoammeters are factory-calibrated and are shipped with all components in place. They are shipped with separate rack angles for rack mounting. Refer to paragraph 2-10 for assembly instructions. The shipping carton also contains the Instruction Manual and mating plugs for the input and the output receptacles.

SECTION 2. OPERATION

2-1. FRONT PANEL CONTROLS. (See Figures 3 and 4.)

a. POLARITY (Model 417). The POLARITY Switch has five positions, including a POWER OFF position. The two METER OFF polarity positions reverse the suppression current polarity and allow the instrument to be used with recorders with the meter disconnected. The other two polarity positions reverse the polarity of the meter as well as the suppression current.

b. POLARITY (Model 416). The POLARITY Switch has four positions. The POWER OFF position shuts off the instrument. The METER OFF position disconnects the meter for recorder operation. The two polarity positions reverse the polarity of the meter.

c. ZERO. The 10-turn ZERO Control allows precise adjustment of the meter to zero on all ranges when the ZERO CK button is depressed.

d. AMPERES FULL SCALE Range Selector. The Range Selector, located on the Input Head, adjusts the meter sensitivity over eight ranges from 10^{-12} to 10^{-5} ampere full scale when the Range MULTIPLIER is set at 1.

e. Range MULTIPLIER. The Range MULTIPLIER selects the full-scale feedback voltage. The dial indicates the factor by which the Range Selector setting is multiplied to determine the meter's full-scale sensitivity. Only the 3 and 1 positions are needed for the 10^{-5} to 10^{-12} ampere ranges. The .3 and the .1 positions extend the sensitivity to 10^{-13} ampere full scale.

f. DAMPING. A variable control on the Input Head adjusts the damping of the feedback circuit from minimum (critical) to a maximum additional rise time of five seconds. Turning counter-clockwise to MIN position locks the control

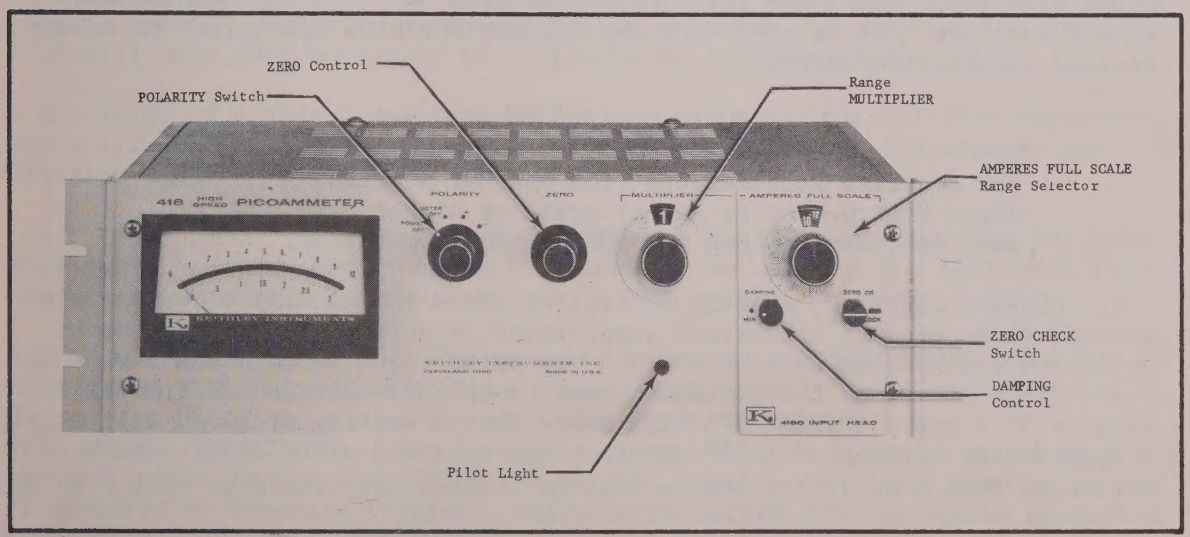


FIGURE 3. Model 416 Front Panel Controls.

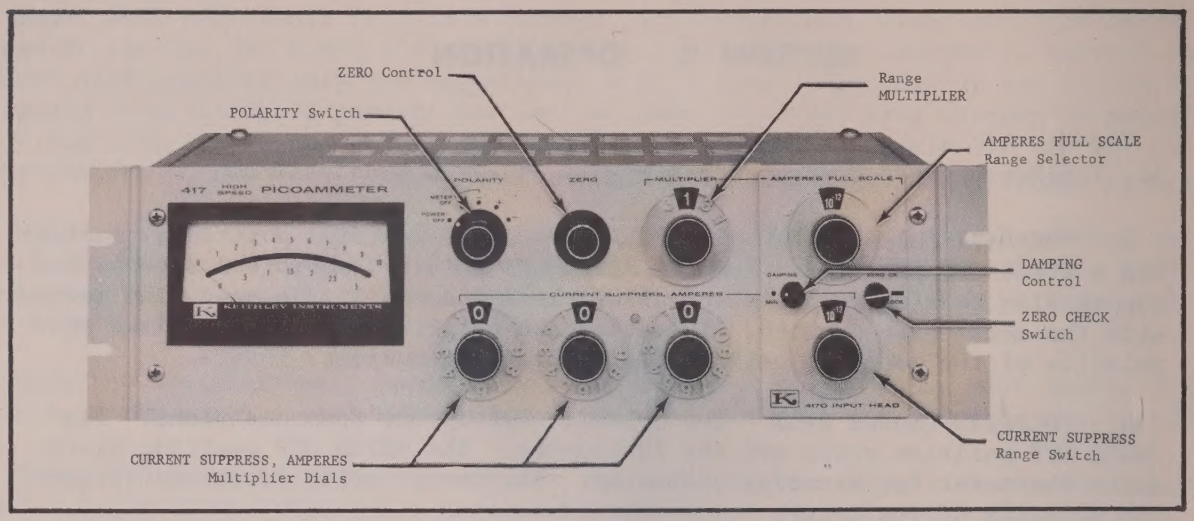


FIGURE 4. Model 417 Front Panel Controls

in the critical damping position. Turning the control clockwise increases damping. The control is effective only for Range Selector settings from 10^{-8} to 10^{-12}.

g. ZERO CK. Depressing the ZERO CK button effectively removes all current from the amplifier input and allows meter zeroing for any range. When the line across the button is horizontal, the switch is locked in the zero check position. Currents greater than 100 times full scale current range may cause some meter deflection in the ZERO CK position.

h. CURRENT SUPPRESS Range Switch (Model 417). This control, located on the Model 4170 Input Head, has seven positions from 10^{-12} to 10^{-6} ampere and an OFF position. It is used with the CURRENT SUPPRESS Multiplier to select the desired suppression current.

NOTE

For accurate measurements, the CURRENT SUPPRESS Range Switch must be set at equal or higher current sensitivity than the AMPERES Range Selector.

i. CURRENT SUPPRESS, AMPERES Multiplier Dials (Model 417). Three dials provide three decades of current suppression adjustment in steps of tens, units and tenths from zero to 100.0. The pilot light between the second and third dials serves as the decimal point. A CURRENT SUPPRESS Multiplier setting of 01.0 and a CURRENT SUPPRESS Range Switch setting of 10^{-10} will supply a suppression current of 10^{-10} ampere. The tens and units dials each have 10 positions from 0 to 9; the tenths dial is continuously variable from 0 to 10.

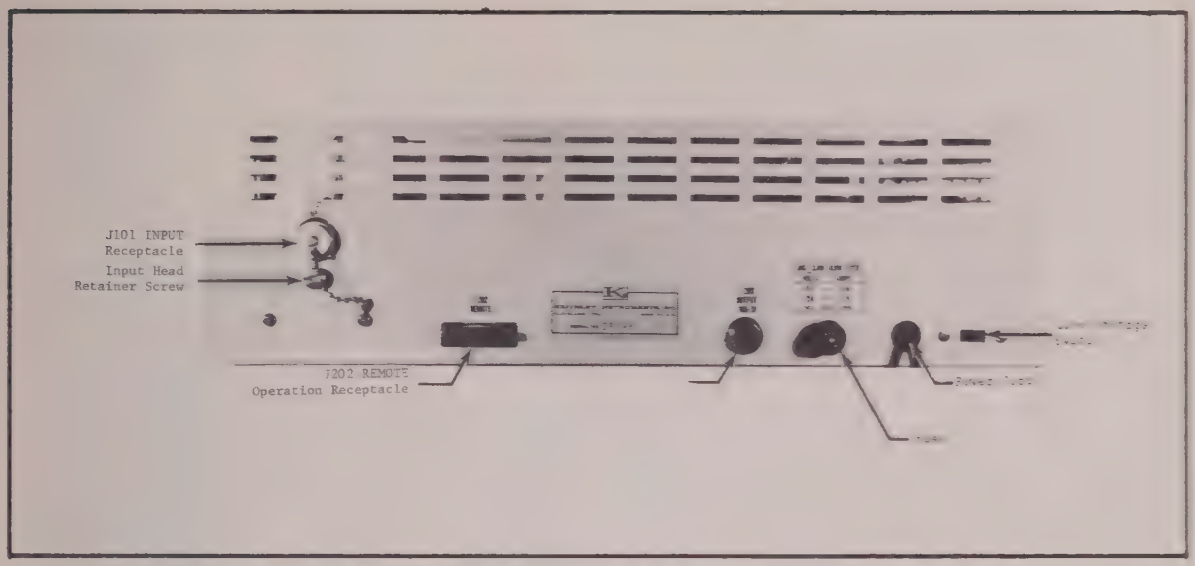


FIGURE 5. Rear Panel Connections for Models 416 and 417.

2-2. REAR PANEL CONNECTIONS. (See Figure 5.)

a. J101 INPUT. A Teflon-insulated uhf-type coaxial input receptacle is provided on the back of the Input Head. It is accessible from the rear of the chassis when the Input Head is in place.

b. J202 REMOTE. A 15-contact receptacle is the mate for one end of the Model 4173 Remote Cable, used to connect the Input Head to the Picoammeter for remote measurements.

c. J203 OUTPUT. A 2-terminal receptacle provides three volts at full-scale meter deflection on all ranges for use with recorders. Pin no. 2 is at chassis ground. Polarity of the output is opposite the input signal polarity. A 50-millivolt 100-ohm output is available on special order.

d. Fuse. A standard 3AG fuse holder is provided. For 117-volt operation, use a 1/2-ampere, 3AG Slo-Blow fuse; for 234 volts, use a 1/4-ampere, 3AG Slo-Blow fuse.

e. Power Cord. The 3-wire power cord with the NEMA approved 3-prong plug provides a ground connection for the cabinet. An adapter for operation from two-terminal outlets is provided.

f. Line Voltage Switch. The screwdriver-operated slide switch sets the Picoammeter for 117 or 234-volt ac power lines.

2-3. INPUT CONNECTIONS. The following considerations apply to connecting the current source to the J101 INPUT receptacle, whether the Input Head is in the Picoammeter or remotely located. Refer to paragraph 2-6 for remote operation procedures.

a. Carefully shield the input connection and the current source being measured, since power line frequencies are well within the pass band of the Picoammeter on all ranges. Unless the shielding is thorough, any alteration in the electrostatic field near the input circuity will cause definite meter disturbances. If power line frequencies cannot be eliminated at the current source, use the DAMPING Control to attenuate these frequencies, so that dc or low-frequency measurements can still be made. (See paragraph 2-4, e.)

b. Use high resistance, low-loss materials — such as polyethylene, polystryene or Teflon — for insulation. Any coaxial cable used should be a low-noise type which employs a graphite coating between the dielectric and the surrounding shield braid. Amphenol-Borg Electronics Corporation, Microdot, Inc., and Simplex Wire and Cable Company make satisfactory types. Using low-noise cable is necessary because the Picoammeter has a wide frequency range.

c. Any change in the capacitance of the measuring circuit to ground will cause extraneous disturbances. Make the measuring setup as rigid as possible, and tie down connecting cables to prevent their movement. If a continuous vibration is present, it may appear at the output as a sinusoidal signal and other precautions may be necessary to isolate the instrument and the connecting cable from the vibration.

2-4. OPERATING PROCEDURES.

a. Connect the power cord to the power source; power line voltage and frequency range are indicated on the rear of the instrument. Turn the power on with the POLARITY Switch and allow five minutes for warmup.

b. Depress and lock the ZERO CK button. Set the POLARITY Switch to + or - (meter on + or - for the Model 417). Set the Range MULTIPLIER to .1 and zero the meter with the ZERO Control. Any range may be used.

NOTE

For the Model 417 only, make sure the CURRENT SUPPRESS Range Switch is OFF. If the switch is in another position, a suppression current can be introduced, causing error in measurements.

c. Set the POLARITY Switch to the polarity of the input signal. Set the Range MULTIPLIER to 3 and the AMPERES Range Selector to the least sensitive position. Release the ZERO CK button (turn in either direction) and advance the AMPERES Range Selector to the most sensitive range for an on-scale reading.

d. If the meter reading is less than 1 on the 0-3 scale, set the Range MULTIPLIER to 1 and read the current on the 0-10 scale. Table 1 contains sample readings.

Range MULTIPLIER Setting	AMPERES, FULL SCALE Range Selector Setting	Meter Scale	Meter Reading	Input Signal (Ampere)
3	10^{-10}	0-3	2.5	2.5×10^{-10}
1	10^{-7}	0-10	9.5	0.95×10^{-7}
.3	10^{-12}	0-3	2.5	0.25×10^{-12}
.1	10^{-12}	0-10	9.5	0.095×10^{-12}

TABLE 1. Sample Control Settings.

e. If extraneous fields produce rapid vibration of the meter pointer, turn the DAMPING Control clockwise from its locked position until the vibration stops. While this decreases the frequency response of the instrument, dc measurements may still be made with no decrease in accuracy. The DAMPING Control is in the circuit only when the AMPERES Range Selector is in the 10^{-8} to 10^{-12} positions.

2-5. SUPPRESSION CURRENT OPERATION.

NOTE

These instructions apply only to the Model 417. The suppression current enables measurements to be made of current fluctuations up to 0.1% of the input signal. It also suppresses steady background signals.

a. For ranges between 3×10^{-5} and 1×10^{-10} ampere full scale, set the CURRENT SUPPRESS Range Switch to a range two decades more sensitive than the current range being used. For ranges between 3×10^{-11} and 3×10^{-12} ampere full scale, set the CURRENT SUPPRESS Range Switch to a range one decade more sensitive. Gradually increase the suppression current with the CURRENT SUPPRESS Multiplier dials until the meter indicates zero.

b. Increase the sensitivity of the AMPERES Range Selector two decades. Adjust the continuously variable last CURRENT SUPPRESS Multiplier dial as the meter's sensitivity is increased. The meter is able to indicate current fluctuations up to 1% of the suppression current. Increasing the sensitivity another decade by setting the Range MULTIPLIER to .1 or .3 will enable the meter to indicate 0.1% fluctuations.

2-6. REMOTE OPERATION. The shunt capacitance introduced by long cable runs from remote installations will considerably lengthen the response time and increase the noise of a fast picoammeter. To maintain short response times and to reduce noise for remote sources, the Input Head, which contains the complete amplifier, can be removed from the instrument and placed at the signal source for measurement.

a. To remove the Input Head from the main chassis, remove the cap from the J101 INPUT receptacle and unscrew the captive retaining screw on the back panel. Pull the Input Head from the chassis through the front panel opening.

b. The Model 4172 Remote Housing provides a secure mounting for the Input Head, although the Input Head can operate remotely as it is. If the Model 4172 is used, insert the Input Head into the Housing. The captive screw on the rear of the Housing secures the Input Head in place. Access holes are located at the rear of the Housing for all connections.

c. Connect the Input Head to the J202 REMOTE receptacle on the Picoammeter, using the Model 4173 Remote Cable. Secure the plugs on the Cable to the mating receptacles with the captive screws provided. The Model 4173 Cable is not sensitive to normally encountered magnetic and electrostatic fields or movements. It will not introduce errors into the measurement. Individual lengths may be connected together. The longest recommended total cable length is 25 feet. If lengths between 25 and 500 feet must be used, adjust the DAMPING Control to prevent oscillations. Oscillations can be detected with an oscilloscope connected to the output terminals or by an offset of the meter zero.

NOTE

Use only the Model 4173 Remote Cable to connect the Input Head to the Picoammeter.

d. The Model 4171 Remote Zero Switch permits zero checking of the Picoammeter when the Input Head is remotely located. The switch is placed through the front panel where the Input Head is normally housed. Connect the cable plug attached to the Model 4171 to the J201 receptacle inside the chassis. Then insert the switch in place on the front panel. Secure the Model 4171 with the two fasteners on the switch panel, turning them counter-clockwise one or two turns, then clockwise until tight.

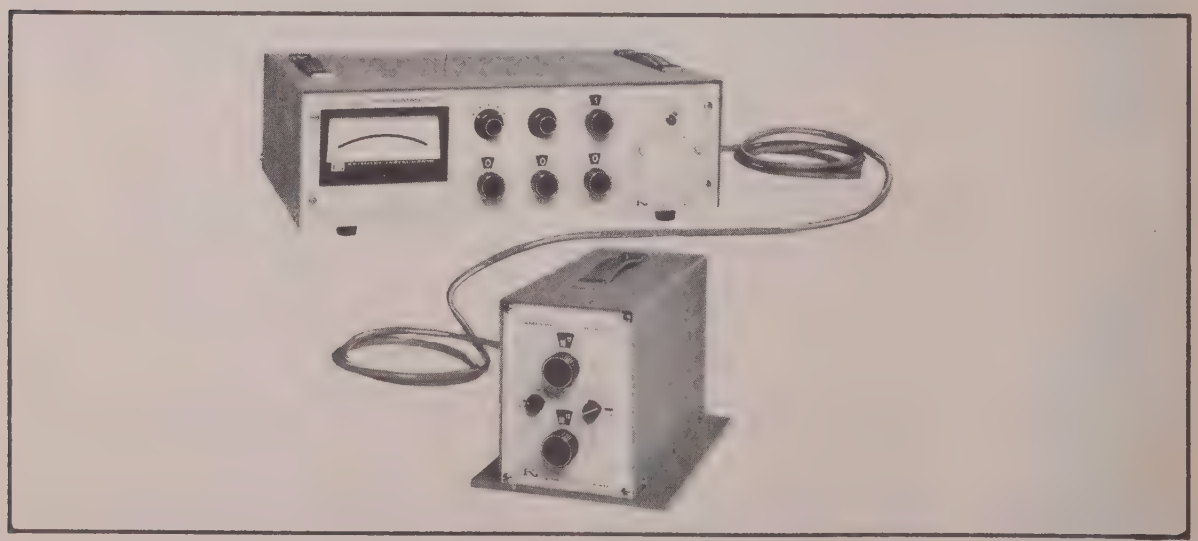


FIGURE 6. Model 417 and Accessories for Remote Operation. The amplifier, contained in the Model 4170 Input Head, is inserted in the Model 4172 Remote Housing. The Model 4171 Remote Zero Switch is shown in the Picoammeter chassis, where the Input Head is normally located. The Picoammeter is shown equipped with the Model 3000 Bench Mounting Kit.

e. The operation of the Picoammeter from a remote location is identical to the procedures outlined in paragraph 2-4.

f. To return the Input Head into the Picoammeter, position the nylon glides on the Head into the chassis. Slide the Head until its front is flush with the Picoammeter front panel. Secure to the chassis with the two retaining screws.

NOTE

When replacing the Input Head in the chassis, only hand-tighten the retaining screw. Excessive tightening may cause the controls to bind.

2-7. RECORDER OUTPUT.

a. The output of the Picoammeter for full-scale meter deflection on any range is ±3 volts at up to one milliampere. The output polarity is opposite the input signal polarity. Pin number 2 is ground. The POLARITY Switch does not reverse the output polarity. The Keithley Model Recorder may be driven directly by the Picoammeter with an output of at least 1 volt at 1 milliampere. The Model 370 is a chart recorder with 10 chart speeds and 1% linearity. The Model 370's input cable has a connector which mates directly with the OUTPUT Connector on the Picoammeter; this avoids interface problems often encountered between a measuring instrument and a recorder. No special wiring is needed. No recorder preamplifier is required.

b. For other outputs, one-milliampere Esterline-Angus and Texas Instruments recorders may be driven directly. To drive 50-millivolt recorders, divide the output with a suitable network across the output. A 50-millivolt output at 100 ohms is available if ordered instead of the ±3 volt output.

c. The value of resistors R252 and R253 (Model 416) and R253 and R254 (Model 417) change according to the recorder output desired. In Table 2, for the Model 416, R252 is R_A and R253 is R_B. For the Model 417, R253 is R_A and R254 is R_B.

Output Voltage	R_A		R_B	
	Value (ohms)	Keithley Part No.	Value (ohms)	Keithley Part No.
1 volt	2 K	R61-2K	1 K	R61-1K
100 mv	2.9 K	R61-2.9K	100	R61-100
50 mv	5.9 K	R61-5.9K	100	R61-100
10 mv	2.99 K	R61-2.99K	10	R61-10

TABLE 2. Resistor Values for Desired Recorder Output. R61 is a metal-film resistor, 0.5%, 1/2 w.

2-8. RISE TIME. As indicated in the specifications, rise time increases with input capacity. Although the input capacity is minimized by the remote operation of the instrument, some is introduced by any connection used. The curves shown in Figure 7 indicate the rise times (from 10% to 90% of final value) for various input capacities and cable lengths.

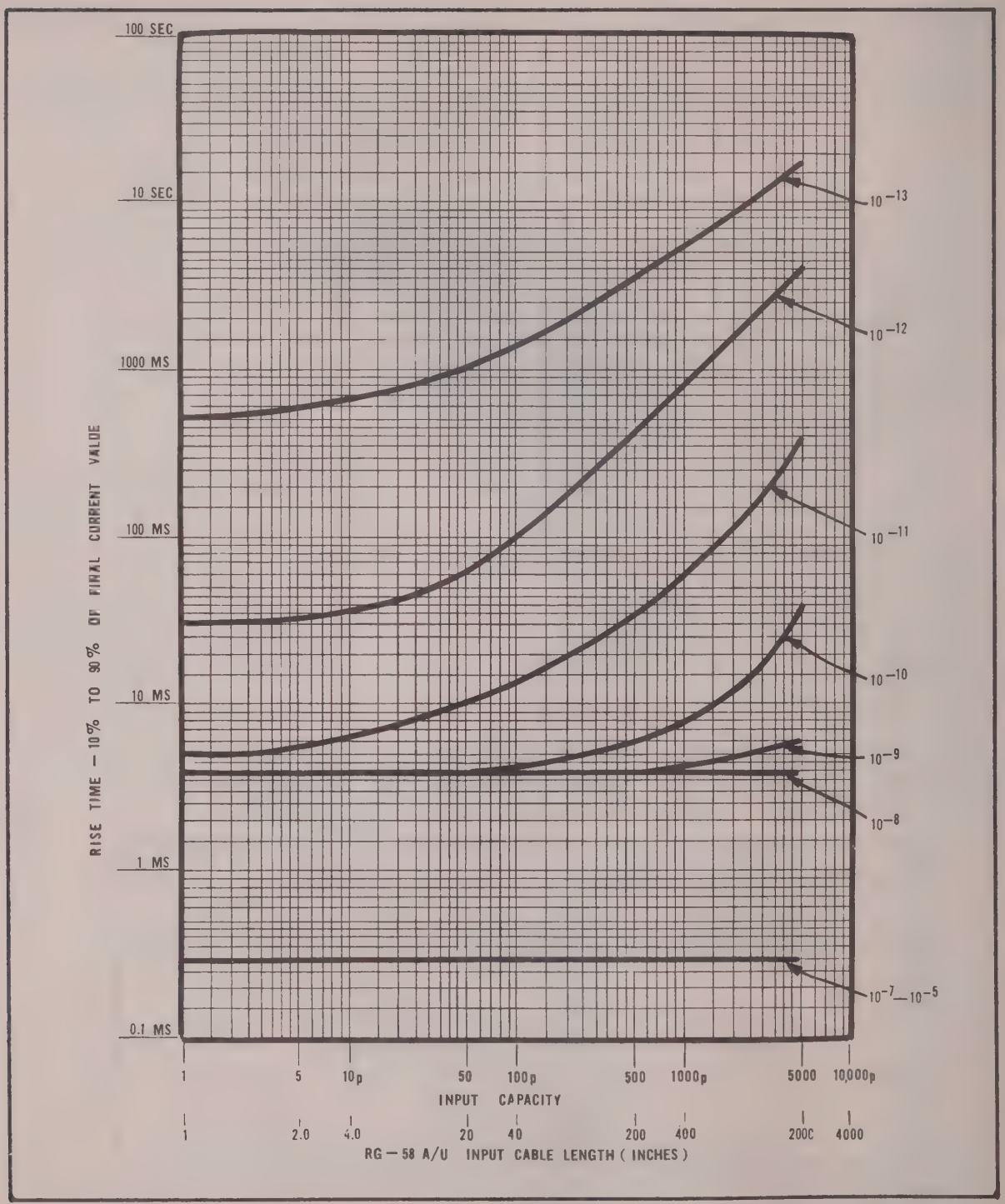


FIGURE 7. Models 416, 417 Rise Times. The graph shows the effect on the rise time over each range of the Picoammeter as the input capacity increases. The equivalent length of coaxial cable (type RG 58A/U) from the source to the amplifier input is shown beneath the input capacity.

2-9. NOISE. Rms output noise is less than 90 millivolts on the most sensitive range, with the DAMPING Control in the minimum position. Increasing the damping reduces the noise to a minimum of 9 millivolts. However, the speed of response is proportionally decreased, since the noise-bandwidth ratio of the instrument remains essentially constant. Decreasing the noise by this method may still prove useful in certain circumstances, as when trying to observe slow changes in extremely small current levels.

NOTE

Further useful operating techniques and applications for the Models 416 and 417 are contained in the brochure "Electrometer Measurements" by Joseph F. Keithley, available upon request from Keithley Instruments, Inc.

2-10. BENCH AND RACK MOUNTING. (See Figure 8.)

a. Adding Rack Angles. The Picoammeter is supplied with all the necessary hardware for standard RETMA 19-inch rack mounting. The rack angles are packed separately to facilitate shipping.

1. Remove the four 10-32 slotted head screws on the sides of the instrument.

2. Place the angles against the instrument sides so that the mounting holes line up. Insert the screws.

b. Bench Mounting Kit. If bench mounting of the Picoammeter is desired, use the Model 3000 Bench Mounting Kit. Assemble as follows:

1. Remove the four 10-32 slotted head screws and, if attached, the rack angles. Remove the top cover assembly (1) by turning the two pawl-type fasteners one-half turn counter-clockwise. Remove the bottom cover assembly the same way.

2. Attach the bail supports (items 3 & 4) to the bottom cover, using two 6-32 x 3/16 Phillips Pan Head screws (item 8).

Item (See Figure 8)	Description	Keithley Part No.	Quantity
1	Cover Assembly with handles	14577C	1
2	Screw, Slotted Head, 10-32 UNC- 2 x 1/4 (Supplied with unit)	---	4
3	Bail Support, Right	14705B	1
4	Bail Support, Left	14703B	1
5	Plastic Foot	FE-5	4
6	Screw, Phillips Head, 8-32 x 7/16	---	4
7	Rubber Foot Insert	FE-6	4
8	Screw, Phillips Head, 6-32 x 1/4	---	2
9	Tilt Bail	14704B	1
-	Cover Assembly, Bottom (Supplied with unit)	14590B	1
-	Screw, Phillips Head, 8-32 x 1/4	---	2
-	Hex Nut, 8-32	---	6
-	Hex Nut, 6-32	---	2
-	Internal tooth lockwasher, #8	---	6
-	Internal tooth lockwasher, #6	---	2

TABLE 3. Model 3000 Bench Mounting Kit Parts List.

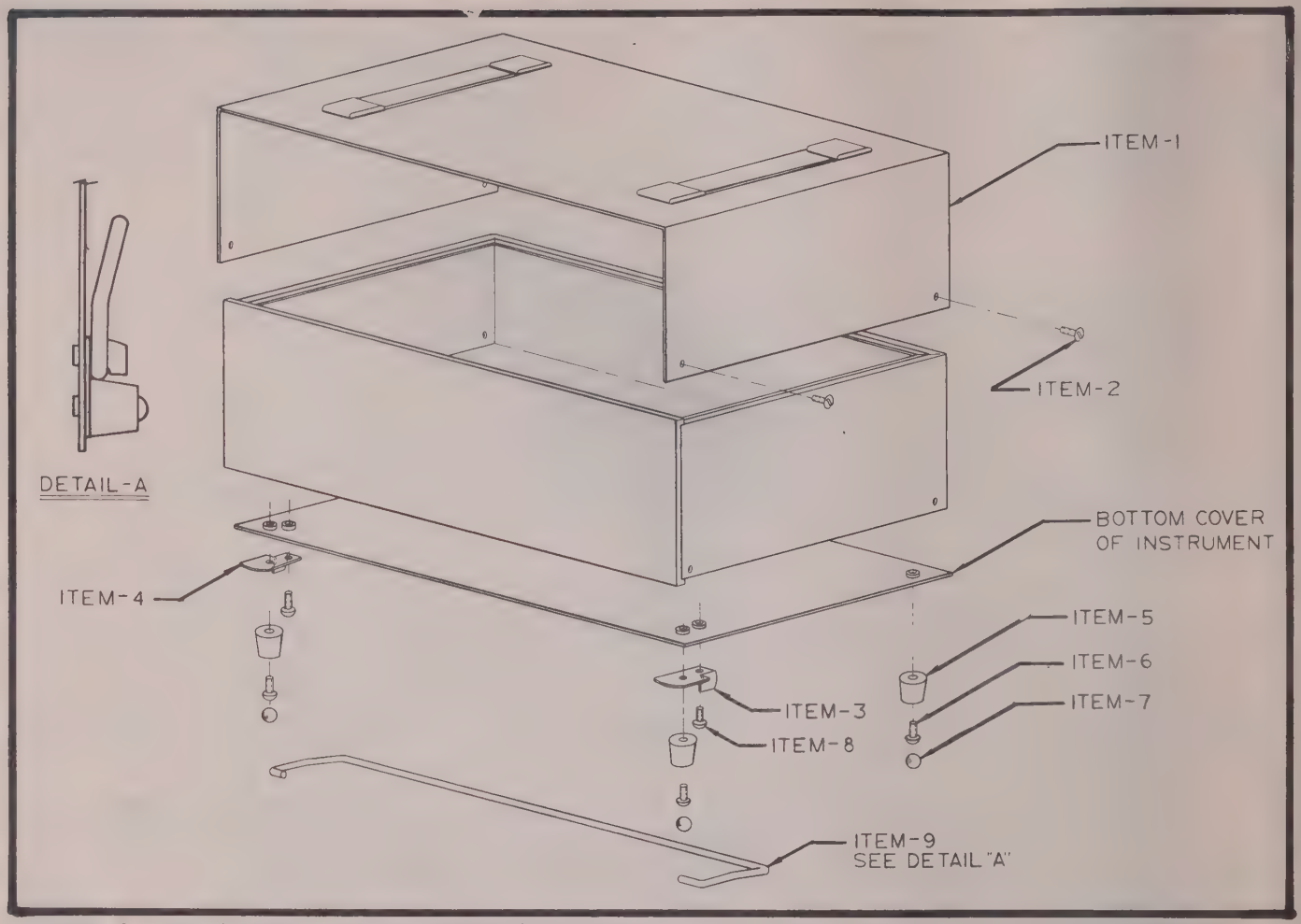


FIGURE 8. Exploded View for Assembling Model 3000. Bench Mounting Kit to Picoammeter.

3. Attach the four feet (item 5), using four 8-32 x 7/16 screws (item 6). Snap the bail (item 9) into place. Push a rubber foot insert (item 7) into each plastic foot.

4. Replace the bottom cover assembly on the instrument and secure in place with the two pawl-type fasteners.

5. Place the bench top cover assembly (item 1) over the instrument. Use the four slotted head screws (item 2) to secure the cover to the instrument at the bottom corners of each side.

2-11. MODEL 6106 ELECTROMETER CONNECTION KIT.

a. The Model 6106 Kit contains a group of the most useful leads and adapters for use in calibrating with the Models 416, 417 and for electrometer measurements in general. The Kit case is 2 inches high x 12 inches wide x 8 inches deep with polyethylene foam compartments. It weighs approximately three pounds.

Item (See Fig. 9)	Description	Keithley Part No.
1	Test Lead, 2 uhf plugs	18265C
2	Binding Post Adapter, uhf plug	Model 6106-2
3	Two Connectors, female uhf to female uhf	CS-5
4	Two Connector Adapters, female uhf to male bnc	CS-172
5	Connector, male uhf to female bnc	CS-115
6	Connector Adapter Tee, two male uhf and one female uhf	CS-171
7	Test Lead, uhf plugs and two alligator clips	Model 6106-1

TABLE 4. Contents of Model 6106 Electrometer Connection Kit.

b. The Kit contains two leads made with 30-inch low-noise coaxial shielded cable (RG58A/U One Lead has two uhf plugs, which allow easy connections between the Model 416, 417 and Keithley picoammeters and electrometers. (See Table 4 for model numbers.) The second lead has a uhf plug and two alligator clips. Adapters are also supplied for uhf-to-bnc conversion.

2-12. 234-VOLT OPERATION. The instrument is shipped for use with a 117-volt power source unless otherwise ordered. To convert the Picoammeters for 234-volt sources, use a screwdriver to change the slide switch on the back panel to the right of the power cord. Change the fuse from 0.5 amp to 0.25 ampere. No other adjustment is necessary. To switch from 234 to 117-volt operation, reverse the procedures. The Picoammeter operates from 50 to 1000 cps without adjustments.

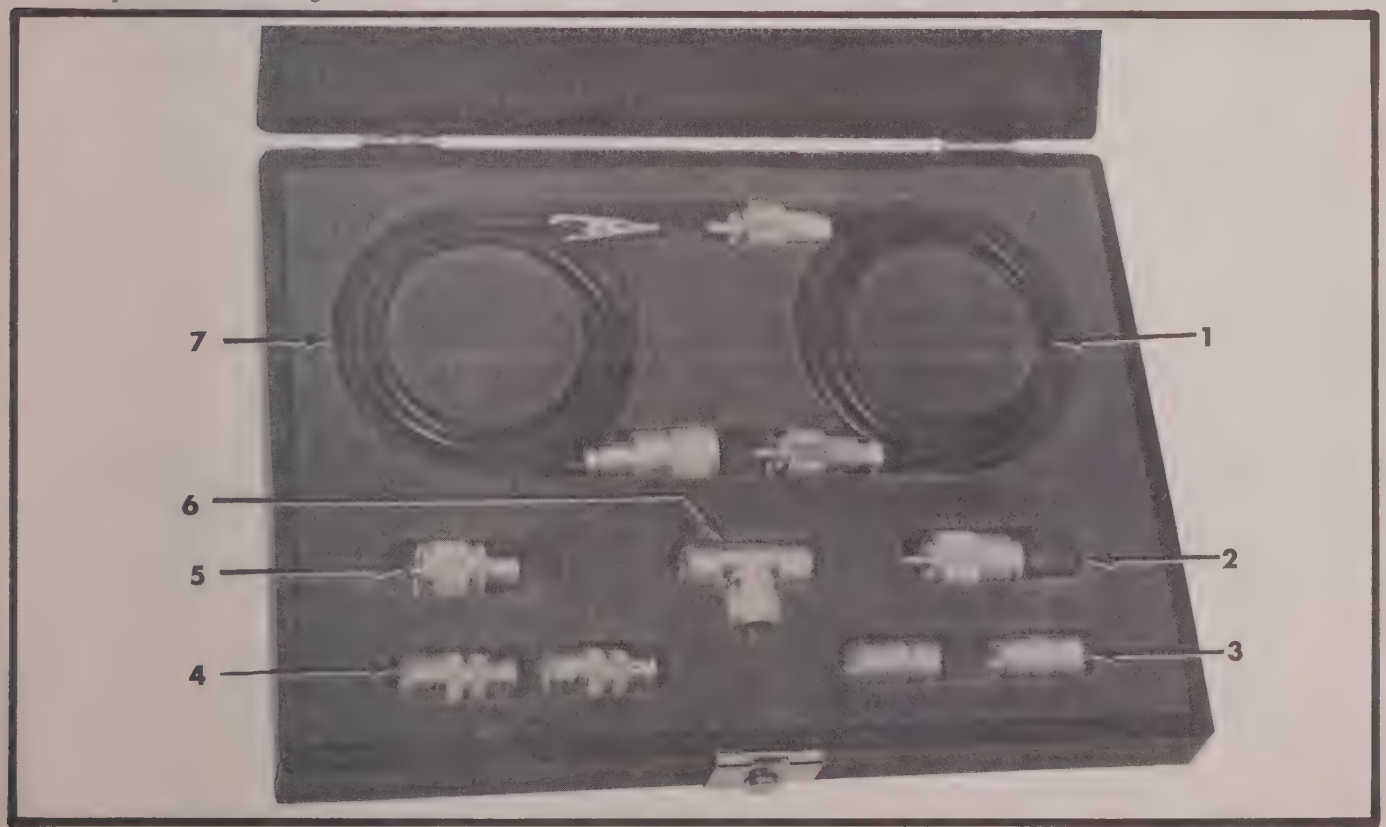


FIGURE 9. Keithley Model Electrometer Connection Kit. Refer to Table 3 for components.

SECTION 3. CIRCUIT DESCRIPTION

3-1. GENERAL. The Models 416 and 417 High-Speed Picoammeters consist principally of a high-gain dc amplifier with a critically-damped feedback network and a super-regulated dc power supply. In addition, the Model 417 contains a current suppression circuit, consisting of a 3-dial Kelvin-Varley divider and a suppression resistor. A dc-dc converter provides an accurate 100-volt potential source for the divider.

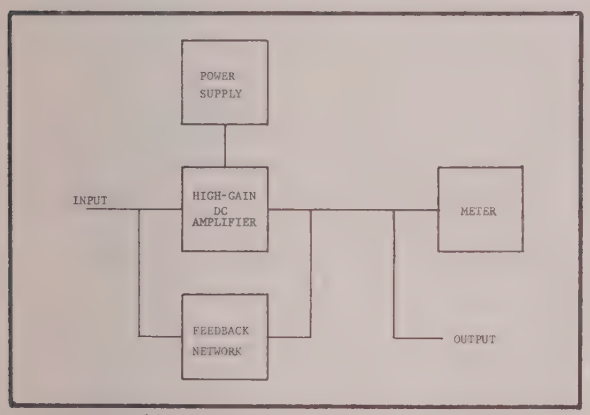


FIGURE 10. Model 416 Block Diagram.

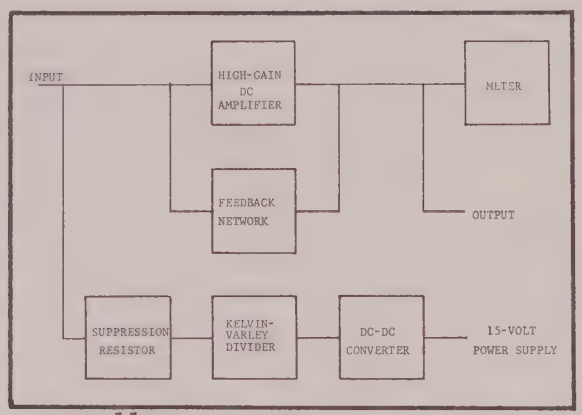


FIGURE 11. Model 417 Block Diagram.

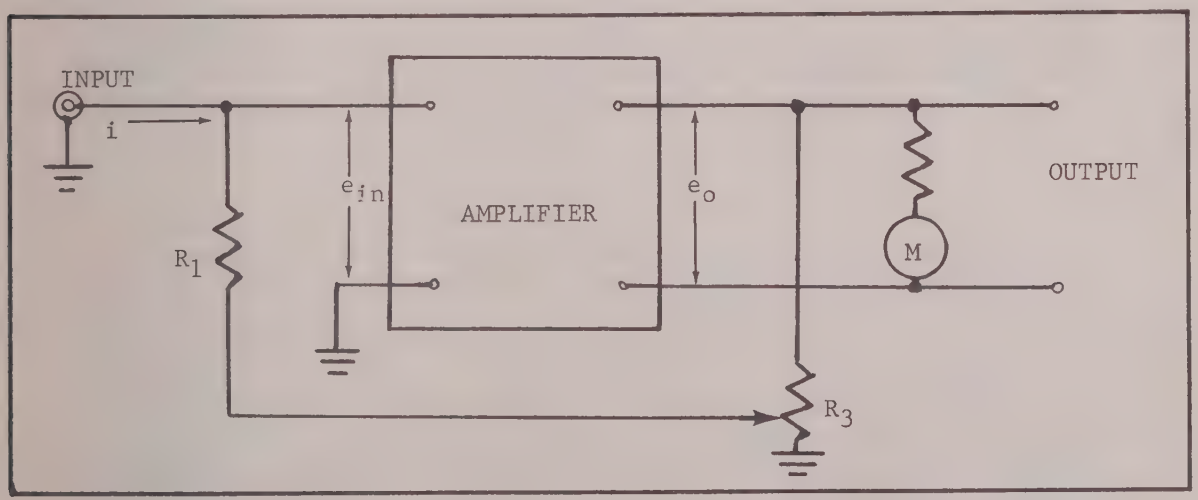


FIGURE 12. Simplified Amplifier and Feedback Circuit for Picoammeters. R_1 is the feedback resistor; R_3 is the multiplier voltage divider; e_{in} is the voltage across the amplifier input; and e_o is the voltage across the amplifier output.

3-2. AMPLIFIER AND FEEDBACK. The amplifier with the feedback circuit is shown in Figure 12. The feedback resistor, R_1, is the resistor selected by the AMPERES Range Selector. The amplifier is designed so that its output is the negative of the input signal. Assuming no current flow into the amplifier input, the input current, i, will flow through the feedback resistor R_1. If the gain of the amplifier is k and the feedback is negative,

$$e_{in} = -e_o/k \qquad \text{Eq. 1}$$

where e_{in} is the voltage across the amplifier input;
e_o is the voltage across the amplifier output;
k is the open-loop gain of the amplifier.

Since the current must flow through R_1

$$i = \frac{-e_o + e_o/k}{R_1} \qquad \text{Eq. 2}$$

If the gain is large — for the Models 416 and 417, the gain is greater than 10,000 — then the current flow is

$$i = -e_o/R_1 \qquad \text{Eq. 3}$$

and a voltmeter at the amplifier output may be calibrated to read current directly.

a. High Gain DC Amplifier. The amplifier, which is completely contained in the Input Head, consists of an electrometer tube input stage, an emitter follower input, a two-stage transistor amplifier and an emitter follower output.

NOTE

The circuit designations referred to in this section are for the Schematic Diagrams 16556F (Model 416) and 16219F (Model 417) found at the back of the Manual.

1. The input signal is applied to the grid of electrometer tube, V101, through an overload network consisting of capacitor C114 and resistor R125. Plate voltage for the electrometer tube is supplied through resistor R126; the filament current of 10 milliamperes is obtained from the +15 volt power supply through resistors R127 and R128. Adjusting potentiometers R130 and R222 zeros the meter by changing the screen voltage.

2. The electrometer tube V101 is directly coupled to the emitter follower, transistor Q101. When the AMPERES Range Selector S102 is in the 10^{-5} to 10^{-7} positions, resistor R131 and capacitor C115 prevent oscillations. The output of Q101 is directly coupled to Q102. Identical transistors Q103 and Q104 provide temperature compensation for the two amplifier stages. The factory-selected resistor R136 adjusts the first stage amplifier gain by varying the emitter degeneration of Q102. The collector of Q102 is directly coupled to

the base of the second stage amplifier, transistor Q105. Emitter bias stabilization is accomplished using the zener diode D101. When the AMPERES Range Selector is in one of the 10^{-8} to 10^{-12} positions, an RC network —capacitor C116 and resistor R134 —between the base and the collector of Q105 prevents oscillations.

3. The output of transistor Q105 is directly coupled to the base of the emitter follower output stage using a power-type transistor Q106. The amplified signal is applied through resistors R250 and R251 to the meter, M201, and the recorder output terminals, J203. The collector of Q106 and the collector resistor, R142, of the second stage amplifier are returned to the -10 volt supply to permit positive and negative outputs. Diode D102 and resistor R145 prevent overloading of the output stage.

b. Feedback Network. The amplifier output is divided by resistors R224 to R227, which comprise the Range MULTIPLIER switch, S202, and is fed back to the amplifier input through one of the range resistors, R108 to R115, selected by positioning the AMPERES Range Selector, S102.

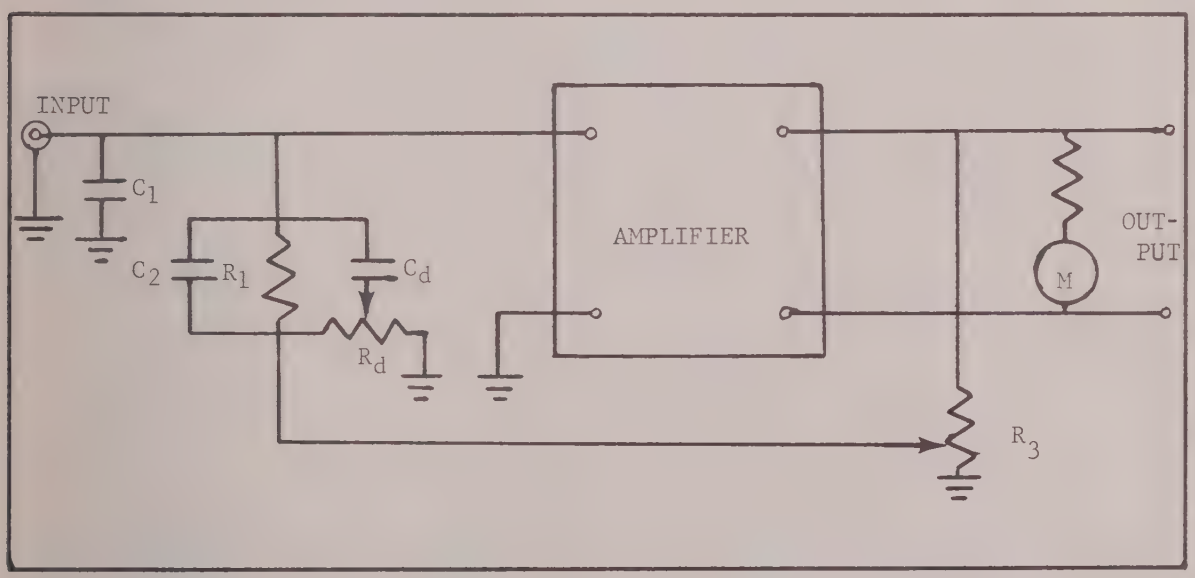


FIGURE 13. Feedback Network with Capacitance Indicated. C_1 is the input capacity; C_2 is the capacity across the feedback resistor; R_1 is the feedback resistor; C_d is the damping capacitance; R_d is the damping resistor.

c. Damping.

1. Referring to Figure 13, the time constant, T, of the circuit is

$$T = R_1\left(\frac{C_1}{1 + k} + C_2\right) \qquad \text{Eq. 4}$$

where C_1 is the input capacity;
R_1 is the feedback resistance in ohms;
C_2 is the capacity across the feedback resistor;
k is the open-loop gain of the amplifier.

Since the gain of the amplifier is greater than 10,000, the effect of the input capacity on the time constant is very small, except at very low currents, and the time constant is determined primarily by the product R_1C_2. With a 10^{12} ohm resistor, which is used on the most sensitive range, this product can amount to 10 seconds.

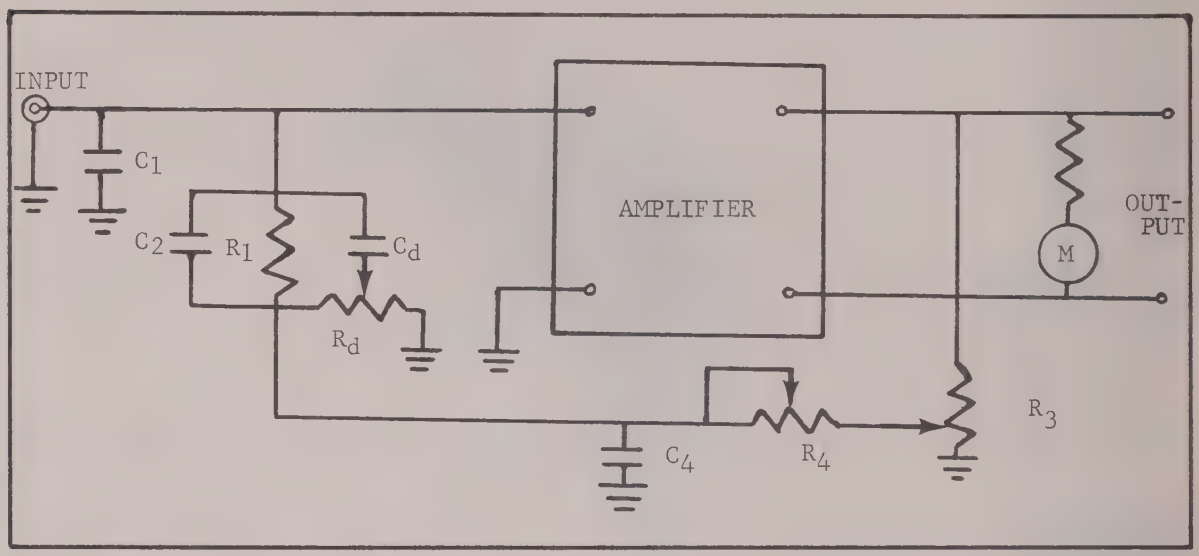


FIGURE 14. Critically Damped Feedback Network. R_4 and C_4 are added to the circuit of Figure 12 so that $R_4C_4 = R_1C_2$.

2. To decrease the effect of R_1C_2, resistor R_4 and capacitor C_4 are added to the circuit. (See Figure 14.) If $R_4C_4 = R_1C_2$, a lead network cancels a lag network and equation 4 becomes

$$T = \frac{R_1 \quad (C_1 + C_2)}{1 + k} \qquad \text{Eq. 5}$$

where both capacities are degenerated by loop gain. With this arrangement, the circuit is critically damped. The addition of more input capacity will affect the time constant. However, critical damping will not be affected, since basically the circuit is a single time-constant feedback system.

3. The DAMPING Control, R124, is in the circuit on the 10^{-8} to 10^{-12} positions of the AMPERES Range Selector, S102.

3-3. POWER SUPPLY. The power supply operates from the line voltage and furnishes +15 and -10 volts to the amplifier and, in the Model 417, +15 volts to the dc-dc converter. Long-term dc stability of the power supply is within 0.1%. Output variations are less than 0.001% for 10% line voltage changes.

a. A 24-volt, 1-ampere output from the power transformer, T201, is rectified by diodes D202 and D203 and is filtered by capacitor C202. The dc voltage across C202 is approximately 22 volts dc. The voltage is applied to the solenoid-operated ZERO Switch, S103, in the Input Head and to the series transistor, Q203.

b. To obtain a stable, accurate voltage, the output of the series transistor, Q203, is regulated by comparing a sample voltage from dividers R213 and R214 to the zener diode reference, D207. If a voltage difference exists, it is amplified by a differential amplifier consisting of transistors Q205 and Q206. The signal is further amplified by transistors Q204, Q201 and Q202. The output of Q202 is applied to the series transistor, Q203, to nullify input variations. Capacitor C205 prevents high-frequency oscillations. The +15 volts at the output of the regulator powers the filament of the electrometer, V101, and of the pilot light. On the Model 417, +15 volts is also supplied to the dc-dc converter circuit.

c. Transistor Q204 operates at a high gain by connecting its collector load to a regulated supply. The circuit permits linear operation of Q203 with widely varying input voltages. To supply Q204, a 117-volt output of transformer T201 is half-wave rectified by diode D201 and is filtered by capacitor C201. Resistor R202 is a dropping resistor. The voltage across the zener diode D204 is a stable -10 volts, which is supplied to resistor R208, the collector load resistor of Q204.

d. Transistors Q202 and Q201 are cascaded emitter followers whose function is to increase the current gain of the series transistor, Q203. Resistors R204 and R207 are added to the circuit to provide stability at high temperatures. Resistors R205 and R209 and diode D205 provide current overload protection. Excessive current drawn from the power supply causes an increased voltage drop across R205, which forward biases diode D205, thus preventing the collector of Q204 from going more negative. Since the collector voltage cannot rise, further amplification is prevented and, therefore, further current increase is prevented.

3-4. CURRENT SUPPRESS CIRCUIT (Model 417 Only). A suppression current is supplied directly at the input terminals of the Model 417. An ultra-stable dc-dc converter in series with a high-megohm resistor supplies the potential. The current is varied by altering the output of the converter with a 3-dial Kelvin-Varley divider and by changing the value of the high-megohm resistor. The stability of the current source makes possible suppression to 1000 full scales. The Kelvin-Varley divider provides readout with a high degree of resolution. No zero shift occurs when changing the sensitivity of the instrument. Currents of either polarity may be suppressed.

a. Dc-Dc Converter. The + 15 volt super-regulated power supply applies a potential to the dc-dc converter, which then provides an extremely stable +100 volts dc to the suppression current circuit.

1. Inductor L201, resistor R215 and capacitor C207 reduce the voltage from the power supply from 15 to 12 volts. The circuit also isolates spikes produced by the dc-dc converter from the + 15 volt supply.

2. Transistors Q207 and Q208 are connected across the +15 volt supply through their emitters and the center tap of the 12-volt winding of transformer T202. The bases receive positive feedback from another winding on T202. Through proper phasing, one transistor is driven to saturation while the other is cut off. This cycle lasts until the core of T202 reaches saturation. At this point, the transformer can no longer keep the operating transistor fully conducting, and its collector current decreases. This causes the polarity of the feedback winding to change, and the previously cut-off transistor now conducts. The other transistor is now cut off. The frequency of oscillation, controlled by the transformer constants, is 40 cps.

3. The potential supplied by transformer T202 is rectified by diodes D208 and D209, and is filtered by capacitor C209 and resistors R218 and R219. The stable 100 volts is then applied to the Kelvin-Varley divider.

b. Kelvin-Varley Divider and Suppression Resistor. The Kelvin-Varley divider is contained in three controls, S203, S204 and R252, and forms a precision divider for the dc-dc converter circuit. The divider selects the suppression voltage in 10 and 1-volt steps from 0 to 100 volts. The full range of the last control corresponds to a change of one volt. The POLARITY Switch, S201, changes the polarity of the suppression voltage to produce a current that is in opposition to the input current polarity. Resistors R101 to R107, which are part of the CURRENT SUPPRESS Range Switch, S101, in series with the output Kelvin-Varley divider, provide seven current ranges of suppression.

SECTION 4. MAINTENANCE

4-1. GENERAL.

a. Section 4 contains the maintenance, troubleshooting and calibration procedures for the Models 416 and 417. It is recommended that these procedures be followed as closely as possible to maintain the accuracy of the instrument.

b. The Models 416 and 417 require no periodic maintenance beyond the normal care required of high-quality electronic equipment. Occasional verification of meter calibration and suppression current calibration (Model 417) should show any need for adjustment. The high-megohm resistor values should be checked every two or three years for specified accuracy on the 10^{-9} to 10^{-12} ampere ranges of the AMPERE Range Selector and the CURRENT SUPPRESS Range switch. Refer to paragraph 4-10.

4-2. PARTS REPLACEMENT. The Replaceable Parts List in Section 5 describes the electrical components of the Picoammeters. Replace components only as necessary. Use only reliable replacements which meet the specifications. The instruments use no matched or critically selected components except for the electrometer tube, V101, which is aged and should be ordered only from Keithley Instruments, Inc.

4-3. TROUBLESHOOTING.

a. The procedures which follow give instructions for repairing troubles which might occur in the Models 416 and 417. Use the procedures outlined and use only specified replacement parts. Table 4 lists equipment recommended for troubleshooting. If the trouble cannot be readily located or repaired, Keithley Instruments will service the instrument at its complete service facilities. Refer to the page at the back of the Manual for shipping instructions.

b. Paragraph 2-10 describes how to remove the cover from the Picoammeter. Table 5 contains the more common troubles which might occur with the instrument. If the repairs indicated in the table do not clear up the trouble, the difficulty will have to be found through a circuit-by-circuit check, such as given in paragraph 4-4. Refer to the circuit description in Section 3 to find the more crucial components and to determine their function in the circuit. The complete circuit schematics, diagrams 16556F (Model 416) and 16219F (Model 417), are found in Section 5.

4-4. PROCEDURES TO GUIDE TROUBLESHOOTING.

a. If the instrument will not operate, check the fuse, line cord, power source and connections between the Input Head and the main chassis. If these are all found satisfactory, use the following procedures to isolate the trouble.

Instrument	Use
General Radio Variac	Check power supply regulation.
Keithley Instruments Model 610B Electrometer	Measure dc voltages.
Keithley Instruments Model 662 Guarded Dc Differential Voltmeter	Check power supply regulation.
Tektronix Model 561A Oscilloscope	Monitor voltage in Model 417 dc-dc Converter.

TABLE 4. Equipment Recommended for Troubleshooting Models 416 and 417.

b. The schematic diagrams indicate all tube element voltages and transistor terminal voltages referenced to chassis ground. Voltages are measured with the Keithley Model 610B Electrometer and should be ± 10% of indicated value. The controls are set as follows to obtain the indicated value:

POLARITY	-
Range MULTIPLIER	1
AMPERES Range Selector	10^{-5}
ZERO CK	Depressed
CURRENT SUPPRESS Range Switch	10^{-6}
CURRENT SUPPRESS Dials	C. W.

c. Power Supply.

1. Remove the Input Head from the main chassis to avoid accidental damage to the amplifier. Loosen the retaining screw beneath the J101 INPUT receptable on the rear panel and pull out the Input Head.

2. Remove transistor Q203 from the circuit and turn on the instrument. Measure the voltage between chassis ground and the can terminal of capacitor C202 with the Model 610B Electrometer. Voltage should be approximately 22 volts dc.

3. Replace transistor Q203 into the circuit. Check the regulation of the power supply by using a General Radio Variac to supply the line voltage. Connect the Model 662 Voltmeter across capacitor C206 and vary the voltage from 105 to 125 volts. The voltage across the capacitor should be +15 volts dc, and it should not vary more than five millivolts with the line voltage changes. If no voltage is present or if the voltage is not properly regulated, check the regulator circuit. Particularly check diode D205 for a short and resistor R205 for an open circuit.

NOTE

When replacing the Input Head in the chassis, only hand tighten the retaining screw. Excessive tightening may cause the controls to bind.

Trouble	Probable Cause	Solution
One range out of calibration.	High-megohm resistor for range is not within specifications.	Refer to paragraph 4-10.
Meter will not zero.	Potentiometer R130 is out of adjustment.	Refer to paragraph 4-5.
Meter out of calibration.	Potentiometer R251 is out of adjustment.	Refer to paragraph 4-11.
	Tube V101 or transistor Q101, Q102 or Q105 defective.	Test and replace faulty component. Check V101 against values in Table 6.
Rise time excessive on one range.	Potentiometer R116, R117 or R118 out of adjustment.	Refer to paragraph 4-12.
Suppression current out of calibration	Resistor R220 is out of adjustment.	Refer to paragraph 4-13.
	Resistors of Kelvin-Varley divider defective.	Check and replace faulty components.
Meter oscillates on 10^{-5} to 10^{-7} ampere ranges.	Resistor R131 or capacitor C115 faulty.	Check and replace faulty components.
Meter oscillates on 10^{-8} to 10^{-12} ranges. Damping is not effective.	Resistor R134 or capacitor C116 Faulty.	Check and replace faulty components.

TABLE 7. Troubleshooting Table.

d. Amplifier.

1. Remove the cover from the Input Head by removing the 10-32 slotted head screws on the back. If available, use the Model 4173 Remote Cable to connect the Input Head to the Picoammeter. Otherwise, insert the Input Head into the chassis, leaving the cover off.

2. Set the Range MULTIPLIER to 1, the AMPERES Range Selector to 10^{-5}, the POLARITY switch to -, and the CURRENT SUPPRESS Range Switch to OFF. Depress and lock the ZERO CK button. Check the voltage across resistor R127 with the Model 610B Electrometer to check the electrometer tube filament current. The voltage should be approximately 2.5 volts. If there is no voltage, replace the electrometer tube.

3. Further troubleshooting of the amplifier is facilitated by defeating the feedback loop. Set the AMPERES Range Selector to 10^{-12} and short the input to ground at the J101 INPUT receptacle. By effectively opening the feedback loop, disturbances near the output of the amplifier have less effect on the input stages.

4. With no feedback, any change in voltage at the input stage of the amplifier is amplified by successive stages, and can be measured with the Model 610B Electrometer. The voltage change at the input stage can be produced by rotating the ZERO control from a complete counter-clockwise position to a complete clockwise position. The first stage which does not produce a voltage change comparable to those shown in Table 6, should be checked for defective components. All voltages are measured from chassis ground. Base connections to the electrometer tube are shown in Figure 15. Check voltages in the order given in Table 6.

Circuit Location	Voltage With ZERO Control Completely Counter-clockwise (Volts)	Clockwise (Volts)
V101 Screen	+10.5	+12.0
V101 Plate	+10.5	+ 6.6
Q101 Emitter	+10.0	+ 5.7
Q102 Collector	+ 9.5	+15.0
Q102 and Q103 Emitters	+ 9.2	+ 7.2
Q103 Base	+ 7.9	no change
Q104 Base	+ 8.5	no change
Q105 Collector	+ 9.6	- 6.8
Q106 Emitter	+ 5.2	- 6.6

TABLE 6. Amplifier Voltage with Feedback Loop Open. Adjusting the ZERO Control will produce the above values in a properly functioning instrument. Voltages should be checked in above order.

e. Current Suppression Dc-Dc Converter. (Model 417 only.)

1. Disconnect the Input Head and connect the Model 561A Oscilloscope to the collector of either transistor Q207 or Q208. (The transistor case is connected to the collector.) Turn the Picoammeter on. The scope should show an approximately 40 cps square wave with a peak-to-peak amplitude of about 20 volts.

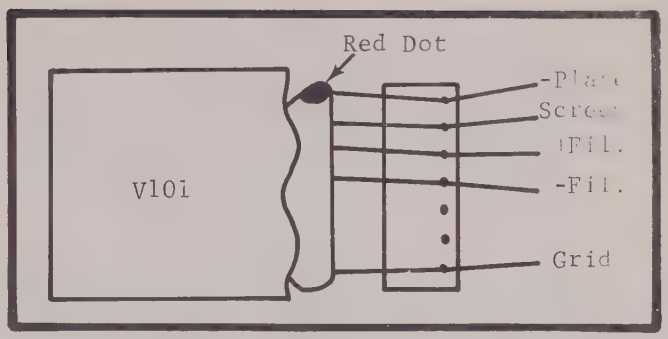


FIGURE 15. Base Connections for Electrometer Tube V101.

2. Measure the voltage between the suppression test jack, J204, and ground. It should be approximately +100 volts dc.

3. If the square wave of B+ potential is missing or not proper, check the components in the dc-dc converter circuit.

4-5. ZERO ADJUSTMENT. The instrument contains two zero controls, an internally located COARSE ZERO potentiometer, R130, and the ZERO Control located on the front panel. A gradual change of electrometer tube characteristics due to aging may require occasional clockwise rotation of the COARSE ZERO potentiometer, R130 (see Figure 18), to enable meter zeroing with the ZERO Control.

4-6. GRID CURRENT CHECK (Model 417). Set the controls as follows:

POLARITY	+
Range MULTIPLIER	0.1
AMPERES Range Selector	10^{-12}
CURRENT SUPPRESS Dials	0 0 0
DAMPING	MIN.

Cap the input of the Model 417. Disengage the ZERO CK Button. Grid current should be less than 2×10^{-4} ampere. Do not suppress the grid current with the ZERO Control. It will unbalance the amplifier. Use the zero suppression circuit of the Model 417 to compensate for the grid current.

4-7. AMPERES RANGE ACCURACY CHECK. This accuracy check serves as a quick surmize whether the Picoammeter is within specification.

a. Set the Picoammeter controls as follows:

POLARITY	+
CURRENT SUPPRESS Dials	0 0 0
DAMPING	MIN.

b. Zero the meter on the 0.1×10^{-12} ampere range.

c. Connect the Model 261 Picoampere source to the Picoammeter and check each range on Picoammeter, from 3×10^{-5} full-scale to 0.1×10^{-12} full scale, by applying an identical full scale current with the Model 261. That is, the setting of the Model 261 should be 3×10^{-8} for a 3×10^{-8} setting on the Model 416 or 417, and so on. The accuracy should be $\pm 2\%$ of full scale on the 3×10^{-5} to 10^{-8} ampere ranges, and $\pm 3\%$ of full-scale on the 3×10^{-9} to 10^{-13} ampere ranges.

4-8. CURRENT SUPPRESSION ACCURACY CHECK (Model 417).

a. Set the Model 417 controls as follows:

POLARITY	+
DAMPING	MIN.
Range MULTIPLIER	1

b. Keep the Model 417 Range MULTIPLIER Switch set to 1. Apply a full scale current to the Model 417 with the Model 261 on each Model 417 range from 1×10^{-5} to 1×10^{-12} ampere.

c. For the 1×10^{-5} to 1×10^{-10} ampere ranges, set the CURRENT SUPPRESS, AMPERES Multiplier Dials to 90.0, and set the CURRENT SUPPRESS Range Switch two decades lower than the concurrent AMPERES FULL SCALE Range Selector setting. For example, if the AMPERES FULL SCALE Range Selector is at 10^{-8}, set the CURRENT SUPPRESS Range Switch to 10^{-10}.

d. For the 1×10^{-11} and 1×10^{-12} ampere ranges, set the CURRENT SUPPRESS Controls to 9.0×10^{-12} and 0.9×10^{-12} respectively.

e. For all the above ranges the Model 417 meter should read zero to within $\pm 5\%$.

4-9. CALIBRATION PROCEDURES.

a. The following procedures are recommended for calibrating the Models 416 and 417. It is also recommended that the equipment listed in Table 7 be used. If proper facilities are not available or if difficulty is encountered, Keithley Instruments can recalibrate the instrument.

b. Four procedures are covered in the following paragraphs: high-megohm resistor verification, meter calibration, transient response measurement, and suppression current calibration. These procedures cover the principal adjustable calibrations which will normally bring the instrument within specifications.

c. If the instrument is not within specifications after performing the calibration procedures, return the unit to Keithley Instruments for further checkout.

Instrument	Use
Wavetek Model 101 Function Generator	Furnish signal for response measurement.
Keithley Instruments Model 261 Picoampere Source	Accuracy check
Keithley Instruments Model 515 Megohm Bridge	Check high-megohm resistor values.
Keithley Instruments Model 662 Guarded DC Differential Voltmeter	Measure voltage for meter calibration and current suppression calibration.
Tektronix Model 561A Oscilloscope	Monitor signal for transient response calibration.
Attenuator, 100:1 and 10:1	Transient response calibration.
5 pf, 200-volt polystyrene capacitor	Transient response calibration.

TABLE 7. Equipment Recommended for Calibration of Models 416 and 417.

4-10. HIGH MEGOHM RESISTOR VERIFICATION.

a. Occasionally, it is necessary to check the value of the high-megohm resistors, R108 to R111 on the AMPERES Range Selector and R101 to R104 on the CURRENT SUPPRESS Range Switch (Model 417). The instrument should be within its rated accuracy for two or three years from the time it leaves the factory. After this, some of the resistors may drift our of tolerance and should be replaced.

b. To check these resistors, it is necessary to use a bridge capable of better than 1% accuracy up to 10^{12} ohms. A megohm bridge, such as the Keithley Instruments Model 515 Megohm Bridge which is accurate to 0.25% for these ranges, is therefore necessary. If such equipment is not available, two procedures are recommended to check out the resistors:

1. Return the complete instrument or just the Input Head to the factory for resistor calibration.

2. Replace the high-megohm resistors periodically with a certified set from Keithley Instruments to assure absolute calibration accuracy.

4-11. METER CALIBRATION.

a. The meter calibration will bring the instrument within the specified accuracy if all circuits are operating properly. The only instrument needed for the calibration is a Model 662 Voltmeter or an equivalent 0.01% instrument.

b. Procedures.

1. Connect the Model 662 Voltmeter to the Picoammeter J203 OUTPUT Receptacle.

2. Set the Picoammeter controls as follows:

POLARITY	+
Range MULTIPLIER	.3
AMPERES Range Selector	10^{-5}
CURRENT SUPPRESS Range Switch	OFF

3. Rotate the ZERO control clockwise until exactly -3 volts (or -50 millivolts on 50-millivolt instruments) is indicated at the output terminal. At this setting, adjust the METER CAL potentiometer R251, located on the main printed circuit board, for full-scale deflection. (See Figure 18.)

4-12. TRANSIENT RESPONSE MEASUREMENT AND CALIBRATION.

a. Before shipping, each instrument is adjusted for optimum rise time on all ranges and should not require further adjustment. Replacement of the high-megohm resistors, electrometer tube or transistors in the amplifier may necessitate an adjustment according to the following procedures.

b. The rise time of the instrument is specified in response to a current step function.

To approximate these conditions, a circuit is used to generate a current step by applying a ramp function to a capacitor. A triangular wave is fed into a capacitor to form a current square wave whose amplitude is

$$I = a\,C$$

where I is the current amplitude;
a is the slope of one segment of the triangular wave in volts per second;
C is the value in farads of the coupling capacitor.

Under these conditions, the signal will be nearly a perfect current step and an oscilloscope at the output will record the true transient response.

c. Procedures.

1. The circuit for the measurement is shown in Figure 16. The output of the Model 202A Low-Frequency Function Generator is attenuated by a voltage divider and applied to the Picoammeter through a 5-picofarad polystyrene capacitor. A Model 561A Oscilloscope is attached to the Picoammeter output. Set the output of the Model 202A at two volts. For adjustment of the 10^{-12} ampere range, use a 100:1 attenuator; for the 10^{-11} ampere range, 10:1 attenuator; and for 10^{-10} ampere range, no attenuation.

2. Set the Model 202A for a triangular wave form at five cps. Set the Picoammeter controls as follows:

POLARITY	+
Range MULTIPLIER	1
AMPERES Range Selector	10^{-10}
DAMPING	MIN.
CURRENT SUPPRESS	OFF

Apply the signal to the Picoammeter and observe the trace on the oscilloscope.

3. Adjust potentiometer R118 (Figure 22) for minimum rise time without overshoot. Typical traces are shown in Figure 17. Observe the trace for the 10^{-11} and 10^{-12} ranges. Adjust potentiometers R117 and R116, respectively, if necessary. The 10^{-9} ampere range is adjusted for optimum rise time by sliding the brass band around the 10^{9} high-megohm resistor, R111 (Figure 24) along the length of the unit.

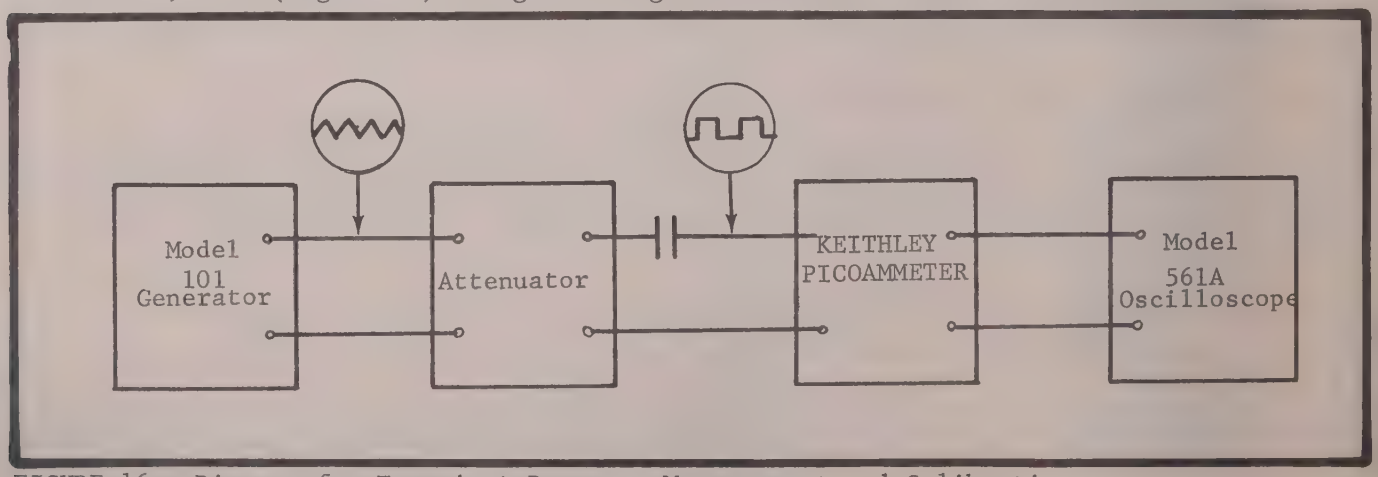
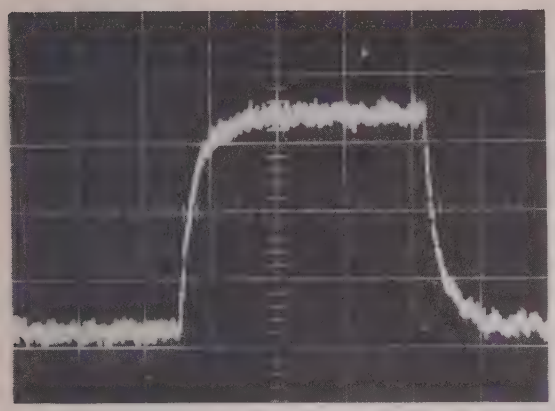
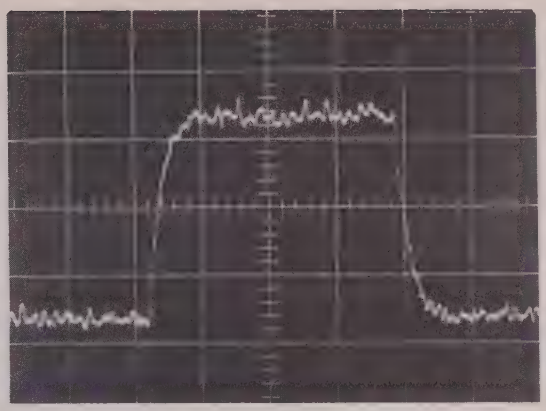


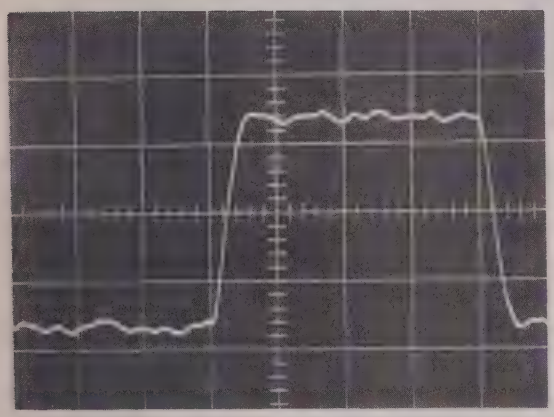
FIGURE 16. Diagram for Transient Response Measurement and Calibration.



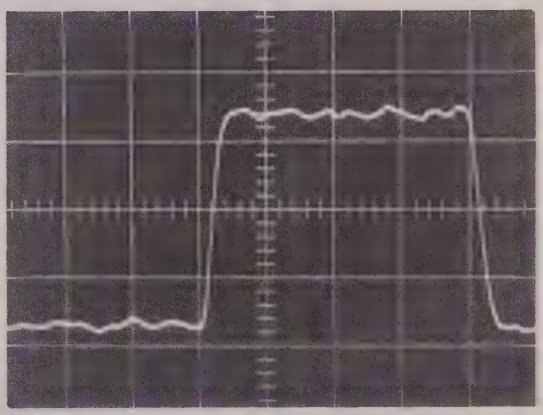
A



B



C



D

FIGURE 17. Typical Rise Time Traces on Oscilloscope. Current square waves of successively increasing amplitude are applied at the input terminals. The input capacitance is approximately five picofarads in each case.

a. Input current is 10^{-13} ampere. Horizontal calibration is 500 milliseconds per division; vertical, one volt per division.

b. Input current is 10^{-12} ampere. Horizontal calibration is 50 milliseconds per division; one volt per division.

c. Input current is 10^{-11} ampere. Horizontal calibration is 10 milliseconds per division; vertical, one volt per division.

d. Input current is 10^{-10} ampere. Horizontal calibration is 10 milliseconds per division; vertical, one volt per division.

4-13. CURRENT SUPPRESSION CALIBRATION (Model 417 only).

a. The current suppression calibration will bring the Model 417 within specifications for the current suppression circuit if the circuits are working properly and the high-megohm resistors, R101 to R104, are within tolerance. The only instrument needed for the calibration is a Model 662 Voltmeter or an equivalent 0.01% instrument.

b. Procedures.

1. Connect the Model 662 Voltmeter to the internal test jack J204 (Figure 19) and to chassis ground.

2. Turn the POLARITY Switch to -. Adjust the CURRENT SUPPRESS CAL potentiometer R220 for +100 volts dc. If the resistors in the Kelvin-Varley divider and the suppression resistor are within their specifications, then the suppression current will be within the Model 417's specifications.

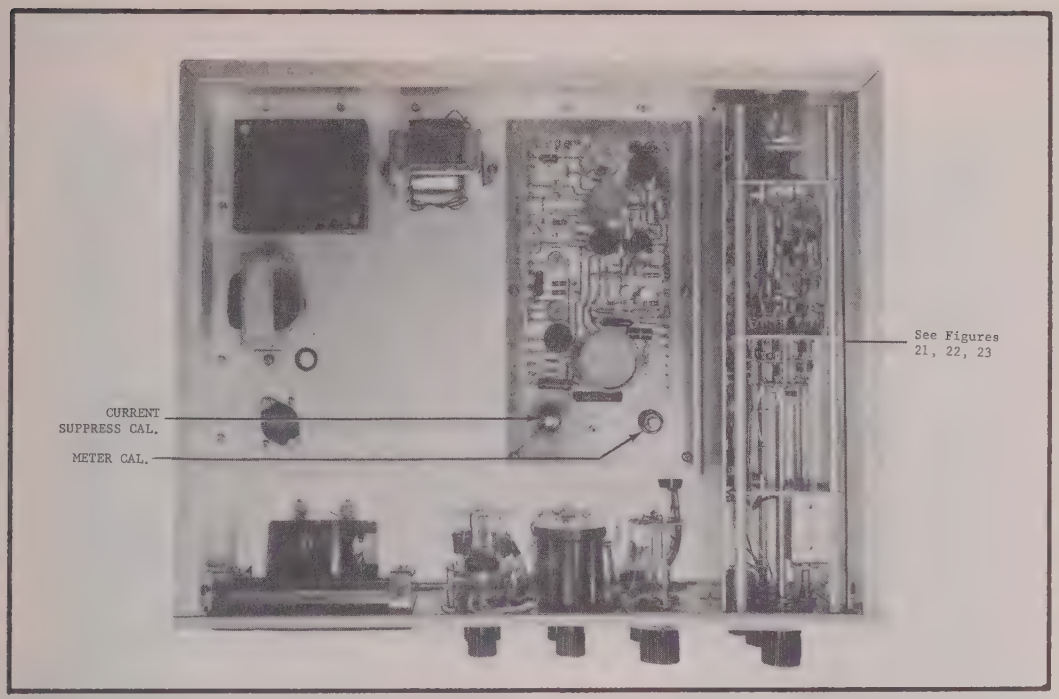


FIGURE 18. Top View of Model 417. Refer to Figure 19 for location of components on main chassis. Equivalent components of Model 416 are located in the same location as on the Model 417.

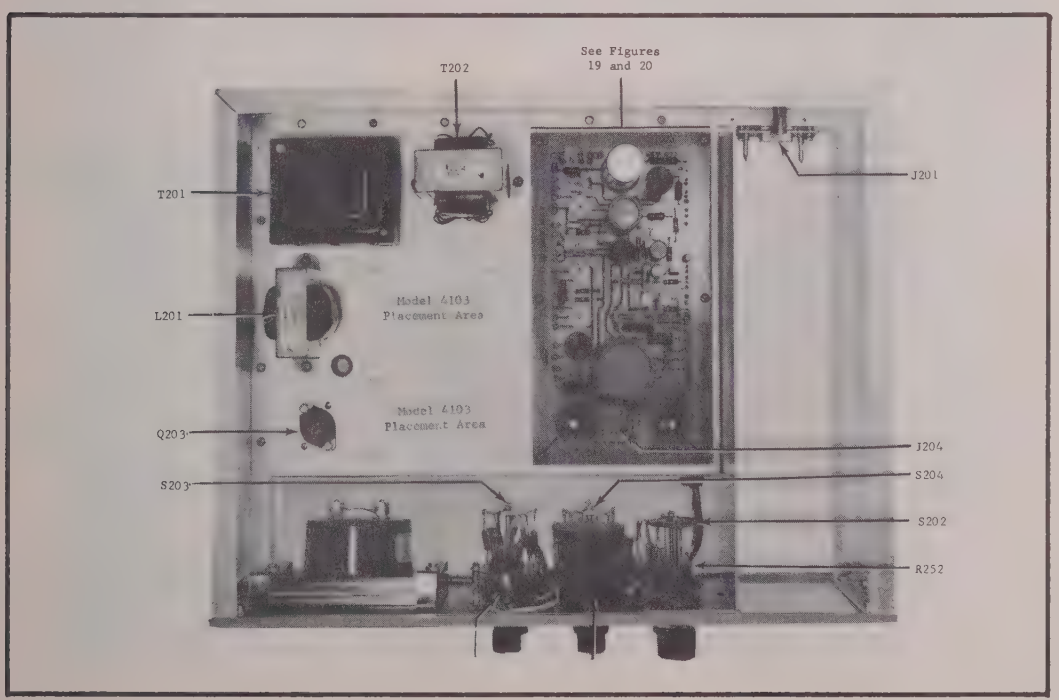


FIGURE 19. Top View of Model 417 Chassis. Circuit designations are for Replaceable Parts List.

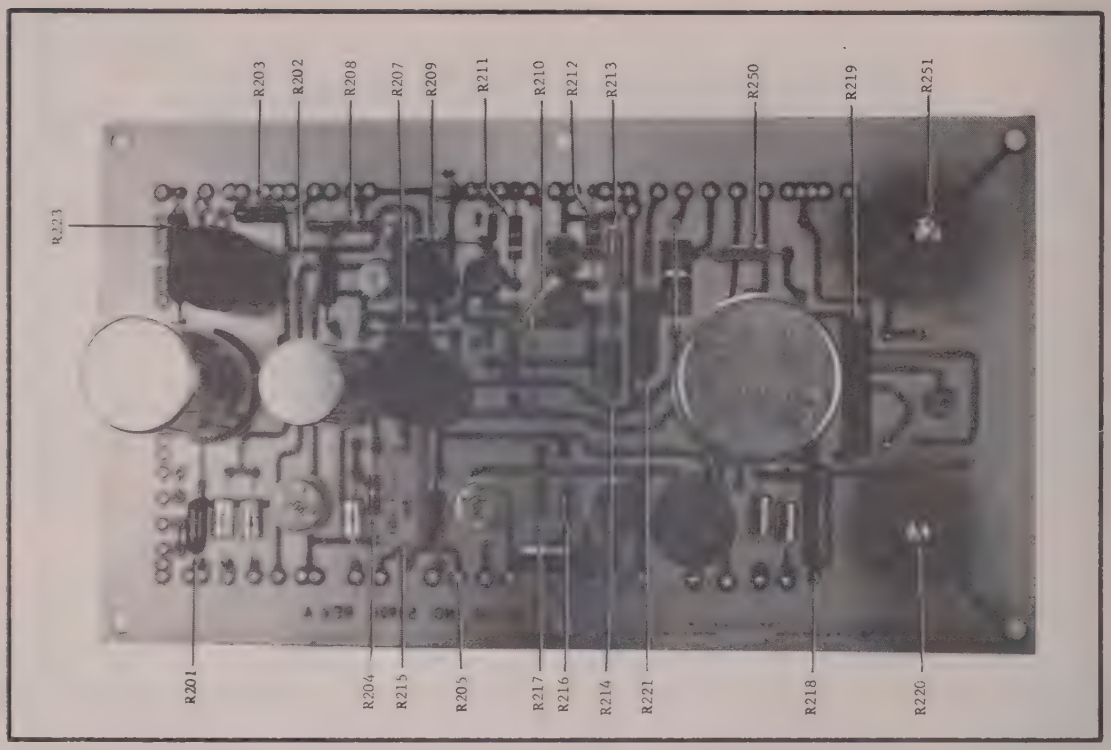


FIGURE 20. Resistors of PC-63, Model 417 Main Chassis.

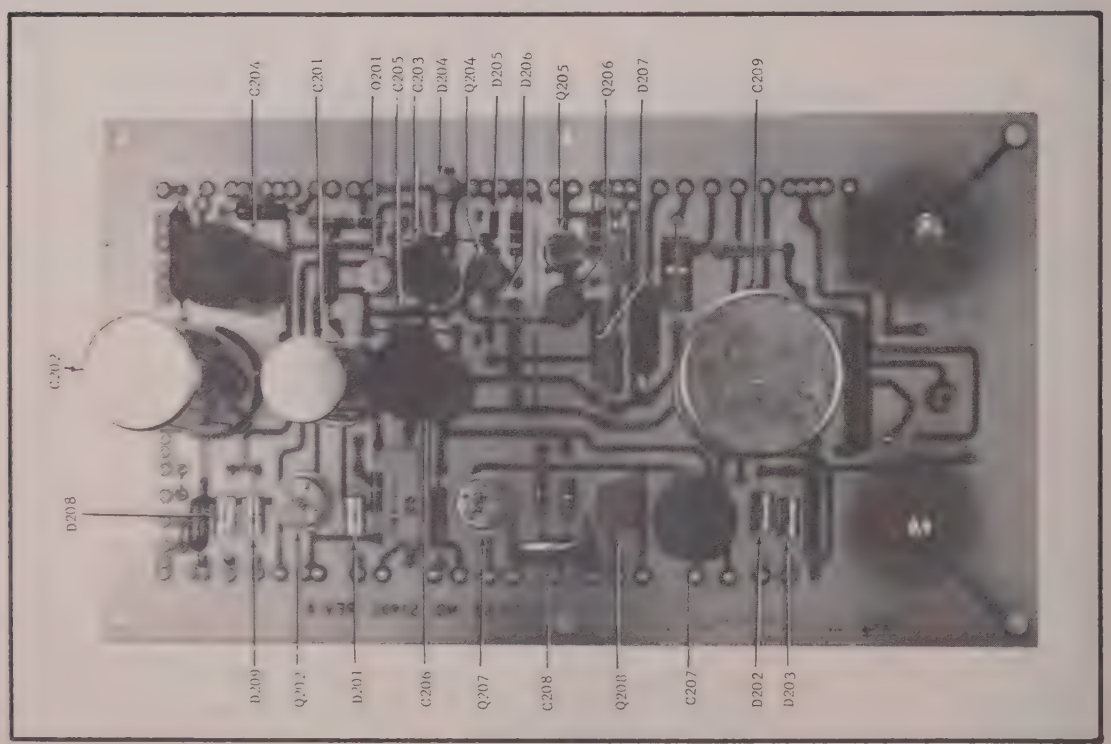


FIGURE 21. Capacitors, Diodes and Transistors on PC-63, Model 417 Main Chassis.

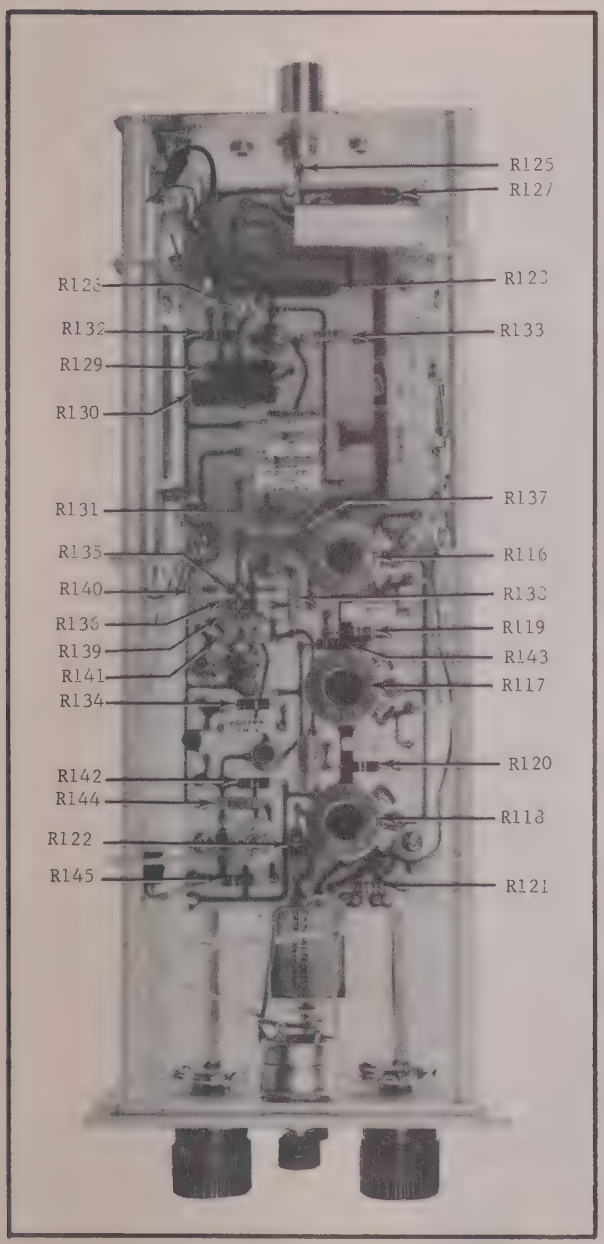


FIGURE 22. Resistors of Model 4170 Input Head.

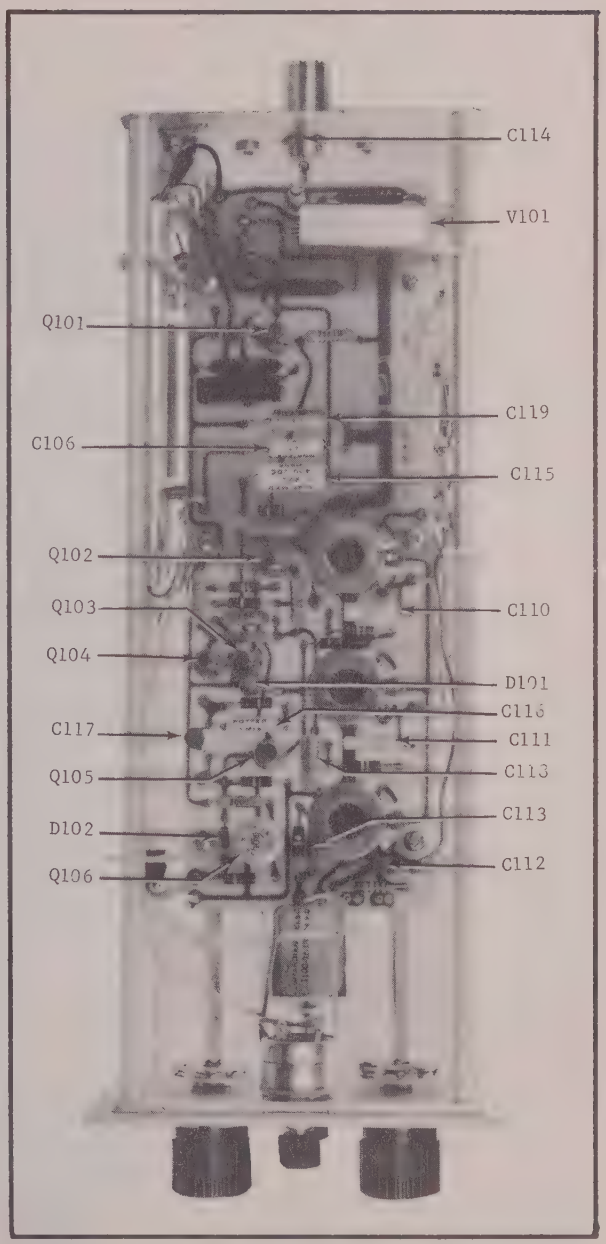


FIGURE 23. Capacitors, Diodes, Tubes and Transistors of Model 4170 Input Head.

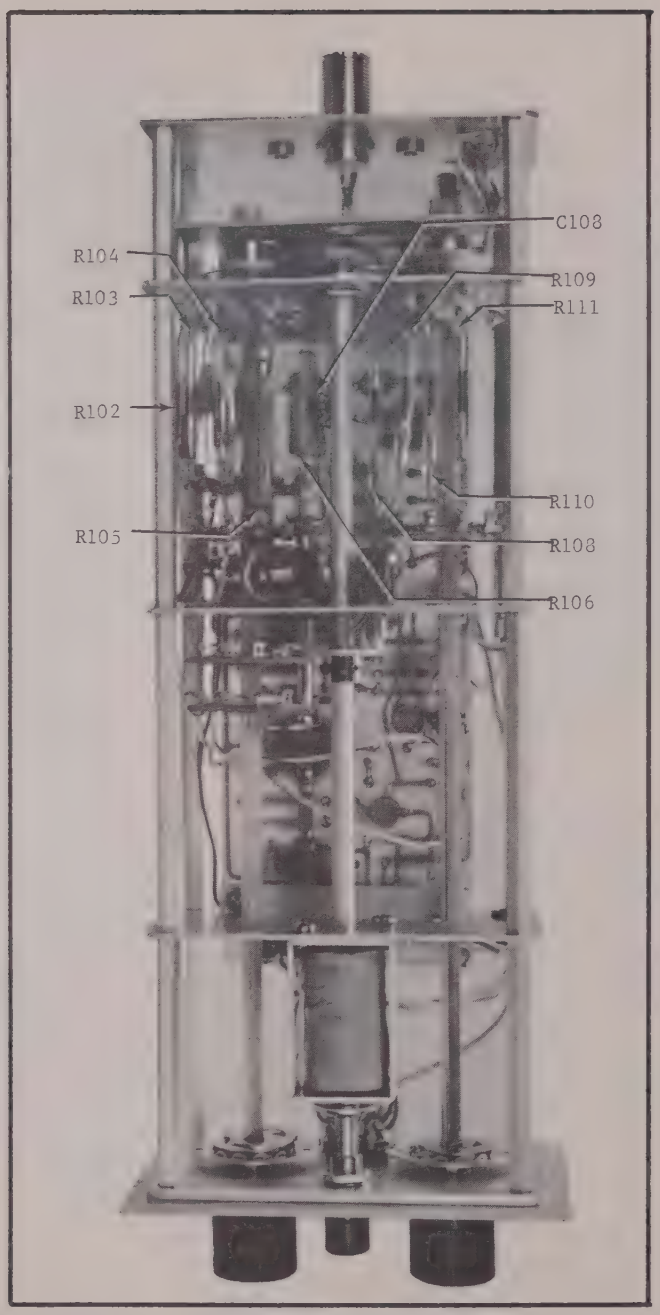


FIGURE 24. Components on Model 4170 Input Head (Side Opposite PC-66).

SECTION 5. REPLACEABLE PARTS

5-1. REPLACEABLE PARTS LIST. The Replaceable Parts List describes the components of the Models 416 and 417 and their accessories. The List gives the circuit designation, the part description, a suggested manufacturer and the Keithley Part Number. The last column indicates on what model the part is used. The name and address of the manufacturers listed in the "Mfg. Code" column are contained in Table 9 .

5-2. HOW TO ORDER PARTS.

a. For parts orders, include the instrument's model and serial number, the Keithley Part Number, the circuit designation and a description of the part. All structural parts and those parts coded for Keithley manufacture (80164) must be ordered from Keithley Instruments, Inc. In ordering a part not listed in the Replaceable Parts List, completely describe the part, its function and its location.

b. Order parts through your nearest Keithley distributor or the Sales Service Department, Keithley Instruments, Inc.

amp	ampere	Mil. No.	Military Type Number
		u	micro (10^{-6})
CerD	Ceramic, Disc	My	Mylar
Comp	Composition		
DCb	Deposited Carbon	PMP	Metalized paper, phenolic case
		Poly	Polystyrene
EMC	Electrolytic, metal cased	p	pico (10^{-12})
f	farad	v	volt
		Var	Variable
k	kilo (10^{3})		
		w	watt
M or meg	mega (10^{6}) or megohms	WW	Wirewound
m	milli (10^{-3})	WWVar	Wirewound Variable
Mfg.	Manufacturer		
MtF	Metal Film		

TABLE 8. Abbreviations and Symbols.

c. In the Replaceable Parts List which follows, see 16556F for the Models 416, 4160 and 4171 Circuit Designations. See 16219F for the Models 417, 4170 and 4171 Circuit Designations.

CAPACITORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.	Used on Model
C101	5 pf	200 v	Poly	00686	C31-5P	4160,4170
C102	47 pf	500 v	Poly	71590	C138-47P	4160,4170
C103	510 pf	500 v	Poly	71590	C138-510P	4160,4170
C104	0.005 uf	500 v	Poly	71590	C138-.005M	4160,4170
C105	0.047 uf	200 v	My	83125	C66-.047M	4160,4170
C106	0.1 uf	200 v	My	83125	C66-.1M	4170
C107	*22 pf	500 v	Poly	71590	C138-22P	4160,4170
C108	10 pf	600 v	CerT	71590	C77-10P	4160,4170
C109	100 pf	600 v	CerD	72982	C21-100P	4160,4170
C110	0.1 uf	200 v	My	83125	C66-.1M	4160,4170
C111	0.01 uf	400 v	My	14655	C114-.01M	4160,4170
C112	0.001 uf	600 v	CerD	72982	C22-.001M	4160,4170
C113	5 pf	600 v	CerD	01121	C22-5P	4160,4170
C114	0.0022 uf	1000 v	CerD	56289	C72-.0022M	4160,4170
C115	0.25 uf	400 v	My	13050	C73-.25M	4160,4170
C116	0.022 uf	400 v	My	13050	C73-.022M	4160,4170
C117	150 pf	600 v	CerD	72982	C22-150P	4160,4170
C118	22 uf	35 v	ETT	05397	C81-22M	4160,4170
C119	22 uf	35 v	ETT	05397	C81-22M	4160,4170
C120	1.5 pf	500 v	CerT	00656	C77-1.5P	4160,4170
C201	40 uf	200 v	EMC	53021	C19-40M	416,417
C202	500/500 uf	35 v	EMC dual	53021	C20-500/500M	416,417
C203	100 uf	15 v	PMP	56289	C93-100M	416,417
C204	500 uf	25 v	PMP	56289	C94-500M	416,417
C205	0.01 uf	600 v	CerD	72982	C22-.01M	416,417
C206	500 uf	25 v	PMP	56289	C94-500M	416,417
C207	500 uf	25 v	PMP	56289	C94-500M	417
C208	0.22 uf	50 v	My	84411	C41-.22M	417
C209	20/40 uf	450 v	EMC dual	56289	C36-40/20M	417
C210	0.047 uf	200 v	My	83125	C66-.047M	416,417
C211	**.0047 uf	600 v	CerD	72982	C22-.0047	416,417

DIODES

Circuit Desig.	Type	Number	Mfg. Code	Keithley Part No.	Used on Model
D101	Zener	1N706	12954	DZ-1	4160,4170
D102	Silicon	1N645	01295	RF-14	4160,4170
D201	Silicon	1N3255	02735	RF-17	416,417
D202	Silicon	1N3256	02735	RF-22	416,417
D203	Silicon	1N3256	02735	RF-22	416,417

*Nominal value, factory selected
**Used only on Models with 50-mv output

DIODES (Cont'd)

Circuit Desig.	Type	Number	Mfg. Code	Keithley Part No.	Used on Model
D204	Zener	1N715	12954	DZ-22	416,417
D205	Silicon	1N645	01295	RF-14	416,417
D206	Silicon	1N645	01295	RF-14	416,417
D207	Zener	1N936	04713	DZ-5	416,417
D208	Silicon	1N3253	02735	RF-20	417
D209	Silicon	1N3253	02735	RF-20	417

MISCELLANEOUS PARTS

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Used on Model
DS201	Bulb, Miniature bayonet base (Mfg. No. 313)	08804	PL-21	416,417
---	Pilot Lamp Holder (Mfg. No. 203CE)	72619	PL-18	416,417
F201 (117v)	Fuse, Slow Blow, 0.5 amp, 3 AG	75915	FU-4	416,417
F201 (234v)	Fuse, Slow Blow, 0.25 amp, 3 AG	75915	FU-17	416,417
---	Fuse holder	75915	FH-3	416,417
J101	Receptacle, uhf, INPUT	80164	CS-134	4160,4170
---	Plug, uhf, Mate of J101, Mil. No. 49190 (Mfg. No. 5127)	91737	CS-49	---
---	Cap for Input Receptacle	91737	CAP-4	---
J102	Plug (Mfg. No. DA-15P)	71468	CS-87	4160,4170
J201, J202	Receptacle Assembly, including receptacle CS-86 (Mfg. No. DA-15S)	80164	17472A	416,417
J203	Receptacle, Microphone, OUTPUT (Mfg. No. 80MC2F)	02660	CS-32	416,417
---	Plug, Microphone, Mate of J203 (Mfg. No. 80MC2M)	02660	CS-33	---
J204	Pin Jack	80164	TJ-4	417
L101	Solenoid	80164	15780B	4160,4170
L201	Choke, 35 mh	80164	CH-3	417
M201	Meter, Taut Band, 0-1 ma	80164	ME-46	416-417
P201	Power Cord, 6 feet	80164	CO-5	416,417
---	Strain Relief	80164	CC-4	416,417
---	3-wire Adapter (accessory)	80164	CO-4	---
P301	Plug (Mfg. No. DA-15P)	71468	CS-87	4171
S101	Rotary Switch, CURRENT SUPPRESS Range	80164	SW-142	4170
---	Dial Assembly, Current Suppress Range Switch	80164	16136A	4170

MISCELLANEOUS PARTS (Cont'd)

Circuit Desig.	Description	Mfg. Code	Keithley Part No.	Used on Model
S102	Rotary Switch, AMPERES, FULL SCALE Range	80164	SW-141	4160,4170
---	Dial Assembly, Amperes Full Scale Range Switch	80164	16130A	4160,4170
S103	Limit Switch, ZERO CK	80164	SW-94	4160,4170
---	Knob Assembly, Zero Check Switch	80164	14376A	4160,4170
S201	Rotary Switch, POLARITY	80164	SW-231	417
---	Knob Assembly, Polarity Switch	80164	14838A	416
---	Knob Assembly, Polarity Switch	80164	20381A & 20382A	417
S202	Rotary Switch, MULTIPLIER	80164	SW-147	416,417
---	Switch Assembly with components, MULTIPLIER	80164	16805B	416,417
---	Dial Assembly, Multiplier Switch	80164	16136A	416,417
---	Switch Assembly with components, CURRENT SUPPRESS Multiplier	80164	16645B	417
S203	Rotary Switch, CURRENT SUPPRESS Multiplier	80164	SW-159	417
---	Dial Assembly, 0-9, Current Suppress Multiplier	80164	14828A	417
---	Switch Assembly with components, CURRENT SUPPRESS Multiplier	80164	16644B	417
S204	Rotary Switch, CURRENT SUPPRESS Multiplier	80164	SW-159	417
---	Dial Assembly, 0-9, Current Suppress Multiplier	80164	14828A	417
S205	Rotary Switch, POLARITY	80164	SW-113	416
S301	Push Switch, ZERO	80164	SW-150	4171
---	Dial Assembly, 0-10, Current Suppress Multiplier	80164	14829A	417
---	Knob, ZERO Control	80164	15110A	416,417
---	Knob Assembly, Damping Control	80164	15868A	4160,4170
---	Slide Switch, 117-234 volt	80164	SW-151	416,417
T201	Power Transformer	80164	TR-59	416,417
T202	Inverter Transformer	80164	TR-86	417

RESISTORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.	Used on Model
R101	10^{12}	+3, -0%	HiMeg	63060	R20-10^{12}	4170
R102	10^{11}	+3, -0%	HiMeg	63060	R20-10^{11}	4170

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.	Used on Model
R103	10^{10} ohm	+3, -0%	HiMeg	63060	R20-10^{10}	4170
R104	10^{9} ohm	+3, 0%	HiMeg	63060	R20-10^{9}	4170
R105	100 Mohm	1%, 2 w	DCb	00327	R14-100M	4170
R106	10 Mohm	1%, 1 w	DCb	00327	R12-10M	4170
R107	1 Mohm	1%, ½ w	DCb	00327	R12-1M	4170
R108	10^{12} ohm	+3, -0%	HiMeg	63060	R20 -10^{12}	4160,4170
R109	10^{11} ohm	+3, -0%	HiMeg	63060	R20 -10^{11}	4160,4170
R110	10^{10} ohm	+3, -0%	HiMeg	63060	R20 -10^{10}	4160,4170
R111	10^{9} ohm	+3, -0%	HiMeg	63060	R20 -10^{9}	4160,4170
R112	100 Mohm	1%, 2 w	DCb	00327	R14-100M	4160,4170
R113	10 Mohm	1%, 1 w	DCb	00327	R12-10M	4160,4170
R114	1 Mohm	1%, ½ w	DCb	00327	R12-1M	4160,4170
R115	100 kohm	1%, ½ w	DCb	00327	R12-100K	4160,4170
R116	2 Mohm	30%, ½ w	CbVar	71450	RP12-2M	4160,4170
R117	2 Mohm	30%, ½ w	CbVar	71450	RP12-2M	4160,4170
R118	2 Mohm	30%, ½ w	CbVar	71450	RP12-2M	4160,4170
R119	*100 kohm	10%, ½ w	Comp	01121	R1-100K	4160,4170
R120	330 kohm	10%, ½ w	Comp	44655	R1-330K	4160,4170
R121	330 kohm	10%, ½ w	Comp	01121	R1-330K	4160,4170
R122	100 kohm	10%, 1/2w	Comp	44655	R1-100K	4160,4170
R123	68 kohm	10%, ½ w	Comp	44655	R1-68K	4160,4170
R124	100 kohm	30%, ¼ w	CbVar	71450	RP36-100K	4160,4170
R125	22 Mohm	10%, ½ w	Comp	01121	R1-22M	4160,4170
R126	121 kohm	1%, 1/2w	DCb	75042	R94-121K	4160,4170
R127	250 ohm	1%, 1 w	WW	15909	R58-250	4160,4170
R128	*1200 ohm	1%, 1 w	WW	15909	R58-1200	4160,4170
R129	1 kohm	1%, 1 w	WW	15909	R58-1K	4160,4170
R130	1 kohm	10%, 1/2w	WWVar	80294	RP39-1K	4160,4170
R131	*220 ohm	10%, 1/2 w	Comp	01121	R1-220	4160,4170
R132	22 kohm	10%, ½ w	Comp	01121	R1-22K	4160,4170
R133	75 kohm	1%, ½ w	DCb	00327	R12-75K	4160,4170
R134	*150 ohm	10%, ½ w	Comp	01121	R1-150	4160,4170
R135	10 kohm	10%, ½ w	Comp	01121	R1-10K	4160,4170
R136	*15 ohm	10%, ½ w	Comp	44655	R1-15	4160,4170
R137	6.8 kohm	1%, ½ w	DCb	00327	R12-6.8K	4160,4170
R138	6.8 kohm	1%, ½ w	DCb	00327	R12-6.8K	4160,4170
R139	75 kohm	1%, ½ w	DCb	00327	R12-75K	4160,4170
R140	3.4 kohm	1%, ½ w	DCb	00327	R12-3.4K	4160,4170
R141	6 kohm	1%, ½ w	DCb	00327	R12-6K	4160,4170
R142	10 kohm	10%, ½ w	Comp	01121	R1-10K	4160,4170

*Nominal value, factory selected

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.	Used on Model
R143	1.8 kohm	10%, ½ w	Comp	01121	R1-1.8K	4160,4170
R144	3.01 kΩ	1%, ½ w	Comp	00327	R1-3.01K	4160,4170
R145	100 ohm	10%, ½ w	Comp	44655	R1-100	4160,4170
R201	3 ohm	5%, 3 w	WW	44655	R92-3	416,417
R202	10 kohm	5%, 3 w	WW	44655	R92-10K	416,417
R203	1 ohm	5%, 3 w	WW	44655	R92-1	416,417
R204	820 ohm	10%, ½ w	Comp	01121	R1-820	416,417
R205	1 ohm	1%, ½ w	DCb	00327	R12-1	416,417
R206	Not Used					
R207	10 kohm	10%, ½ w	Comp	01121	R1-10K	416,417
R208	10 kohm	10%, ½ w	Comp	01121	R1-10K	416,417
R209	1.2 kohm	10%, ½ w	Comp	44655	R1-1.2K	416,417
R210	680 ohm	10%, 1/2w	Comp	44655	R1-680	416,417
R211	3.9 kohm	10%, ½ w	Comp	01121	R1-3.9K	416,417
R212	3.9 kohm	10%, ½ w	Comp	01121	R1-3.9K	416,417
R213	499 Ω	1%, ½ w	DCb	00327	R12-499	416,417
R214	806 Ω	1%, ½ w	DCb	00327	R12-806	416,417
R215	25 ohm	10%, 5 w	WW	94310	R4A-25	417
R216	2.2 kohm	10%, ½ w	Comp	44655	R1-2.2K	417
R217	150 ohm	10%, ½ w	Comp	01121	R1-150	417
R218	20 kohm	5%, 5 w	WW	94310	R4A-20K	417
R219	7 kohm	10%, 5 w	WW	94310	R4A-7K	417
R220	15 kohm	10%, 2 w	WWVar	71450	RP3-15K	417
R221	470 ohm	1%, 1 w	WW	15909	R58-470	416,417
R222	200 ohm	3%, 5 w	WWVar	73138	RP4-200	416,417
R223	550 ohm	1%, 1 w	WW	15909	R58-550	416,417
R224	2 kohm	0.5%, 1/2w	MtF	75042	R61-2K	416,417
R225	700 ohm	0.5%, 1/2w	MtF	75042	R61-700	416,417
R226	200 ohm	0.5%, 1/2w	MtF	75042	R61-200	416,417
R227	100 ohm	0.5%, 1/2w	MtF	75042	R61-100	416,417
R228 to R238	2.5 kohm	1%, 1/2 w	DCb	00327	R12-2.5K	417
R239 to R249	499 Ω	1%, 1/2 w	DCb	00327	R12-499	417
R250	2.5 kohm	1%, 1/2 w	DCb	00327	R12-2.5K	416,417
R251	1 kohm	20%, 2 w	WW	71450	RP50-1K	416,417
R252	1 kohm	10%, 2 w	WWVar	71450	RP3-1K	417
R253&R254	See Section 2-7.					
R254*	200 ohm	20%, 2 w	WW	71450	RP50-200	416
R255**	200 ohm	20%, 2 w	WW	71450	RP50-200	417

* Model 416 designation only
** Model 417 designation only

TRANSISTORS

Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Used on Model
Q101	A1380	73445	TG-32	4160,4170
Q102	A1380	73445	TG-32	4160,4170
Q103	A1380	73445	TG-32	4160,4170
Q104	A1380	73445	TG-32	4160,4170
Q105	2N651	04713	TG-9	4160,4170
Q106	2N1183	02735	TG-11	4160,4170
Q201	2N1381	01295	TG-8	416,417
Q202	2N1183	02735	TG-11	416,417
Q203	2N1535	04713	TG-7	416,417
Q204	2N1381	01295	TG-8	416,417
Q205	2N1381	01295	TG-8	416,417
Q206	2N1381	01295	TG-8	416,417
Q207	2N1183	02735	TG-11	417
Q208	2N1183	02735	TG-11	417

VACUUM TUBES

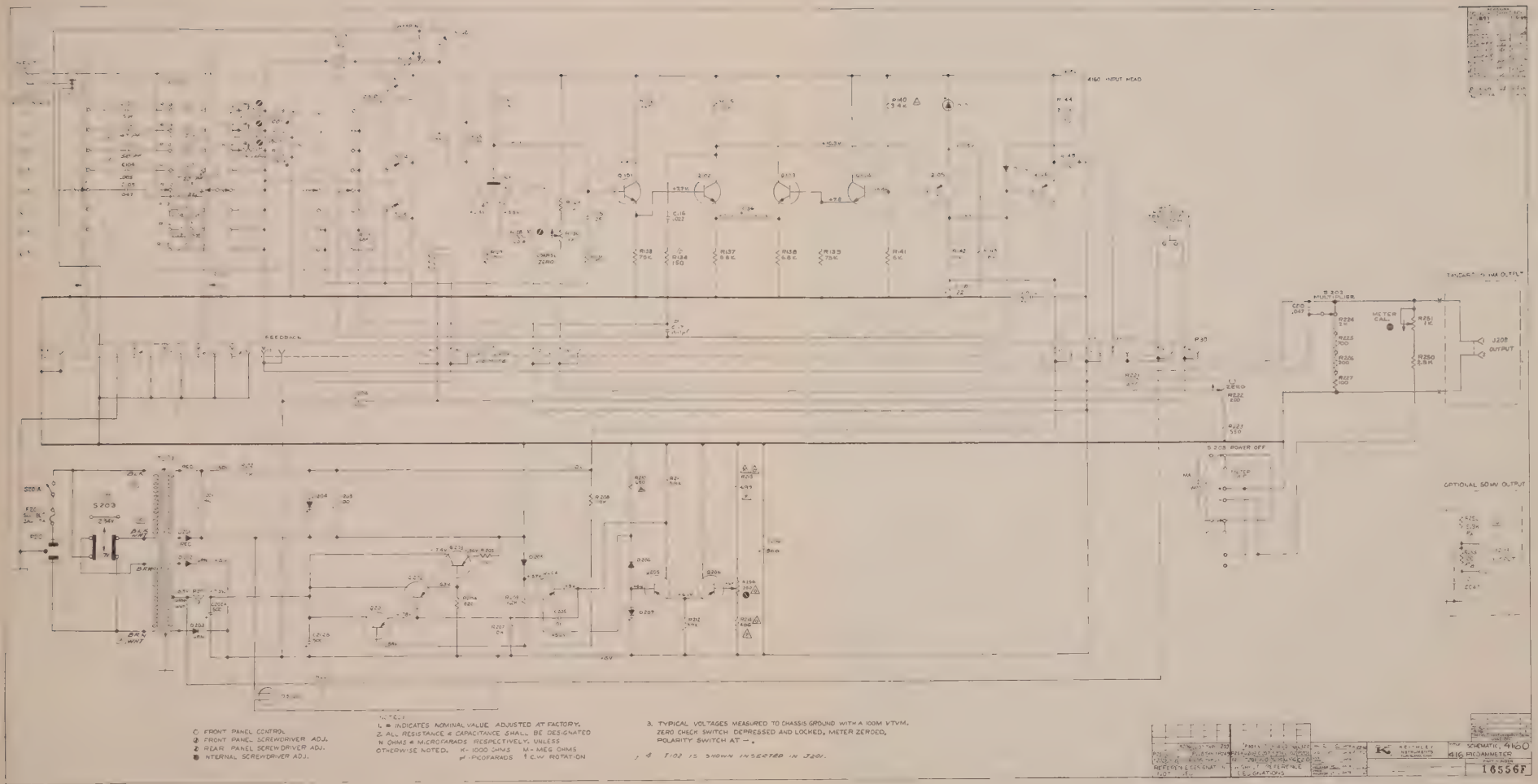
Circuit Desig.	Number	Mfg. Code	Keithley Part No.	Used on Model
V101	5886	80164	EV-5886-2X	4160,4170

00327	Welwyn International, Inc. Cleveland, Ohio	02735	Radio Corp. of America RCA Semiconductor & Materials Div. Somerville, N. J.
00656	Aerovox Corp. New Bedford, Mass.	04713	Motorola, Inc. Semiconductor Products Div. Phoenix, Ariz.
00686	Film Capacitors, Inc. New York, N. Y.	05397	Kemet Co. Cleveland, Ohio
01121	Allen-Bradley Corp. Milwaukee, Wis.	07716	International Resistance Co. Burlington, Iowa
01295	Texas Instruments, Inc. Semi-Conductor Products Div. Dallas, Texas	08804	General Electric Co. Lamp Division Cleveland, Ohio
02660	Amphenol Connector Division Amphenol-Borg Electronics Corp. Chicago, Illinois		

TABLE 9 (Sheet 1). Code List of Suggested Manufacturers. (Based on Federal Supply Code for Manufacturers, Cataloging Handbook H4-1.)

12954	Dickson Electronics Corp. Scottsdale, Ariz.
13050	Potter Co. Wesson, Miss.
14655	Cornell-Dubilier Electric Corp. Newark, N. J.
15909	Daven Co. Livingston, N. J.
44655	Ohmite Mfg. Co. Skokie, Ill.
53021	Sangamo Electric Co. Springfield, Ill.
56289	Sprague Electric Co. North Adams, Mass.
63060	Victoreen Instrument Co. Cleveland, Ohio
71450	CTS Corp. Elkhart, Ind.
71468	Cannon Electric Co. Los Angeles, Calif.
71590	Centralab Division of Globe-Union, Inc. Milwaukee, Wis.
72619	Dialight Corp. Brooklyn, N. Y.
72982	Erie Technological Products, Inc. Erie, Pa.
73138	Helipot Division of Beckman Instruments, Inc. Fullerton, Calif.
73445	Amperex Electronic Corp. Hicksville, N. Y.
75042	International Resistance Co. Philadelphia, Pa.
75915	Littelfuse, Inc. Des Plaines, Ill.
77764	Resistance Products Co. Harrisburg, Pa.
80164	Keithley Instruments, Inc. Cleveland, Ohio
80294	Bourns Laboratories, Inc. Riverside, Calif.
83125	General Instrument Corp. Capacitor Division Darlington, S. C.
84411	Good-All Electric Mfg. Co. Ogallala, Nebr.
91737	Gremar Mfg. Co., Inc. Wakefield, Mass.
94145	Raytheon Co. Semiconductor Division California Street Plant Newton, Mass.
94310	Tru Ohm Products Div. of Model Engineering and Mfg., Inc. Chicago, Ill.
99942	Hoffman Electronics Corp. Semiconductor Division El Monte, Calif.
9999A	Advanced Micro-Electronics, Inc. Cranston, R. I.

TABLE 9 (Sheet 2). Code List of Suggested Manufacturers. (Based on Federal Supply Code for Manufacturers, Cataloging Handbook H4-1.)



C FRONT PANEL CONTROL
2 FRONT PANEL SCREWDRIVER ADJ.
2 REAR PANEL SCREWDRIVER ADJ.
● INTERNAL SCREWDRIVER ADJ.

NOTES:
1. ● INDICATES NOMINAL VALUE ADJUSTED AT FACTORY.
2. ALL RESISTANCE & CAPACITANCE SHALL BE DESIGNATED IN OHMS & MICROFARADS RESPECTIVELY, UNLESS OTHERWISE NOTED. K= 1000 OHMS M= MEG OHMS μμF=PICOFARADS ↑ C.W. ROTATION
3. TYPICAL VOLTAGES MEASURED TO CHASSIS GROUND WITH A 100M VTVM, ZERO CHECK SWITCH DEPRESSED AND LOCKED, METER ZEROED, POLARITY SWITCH AT —.

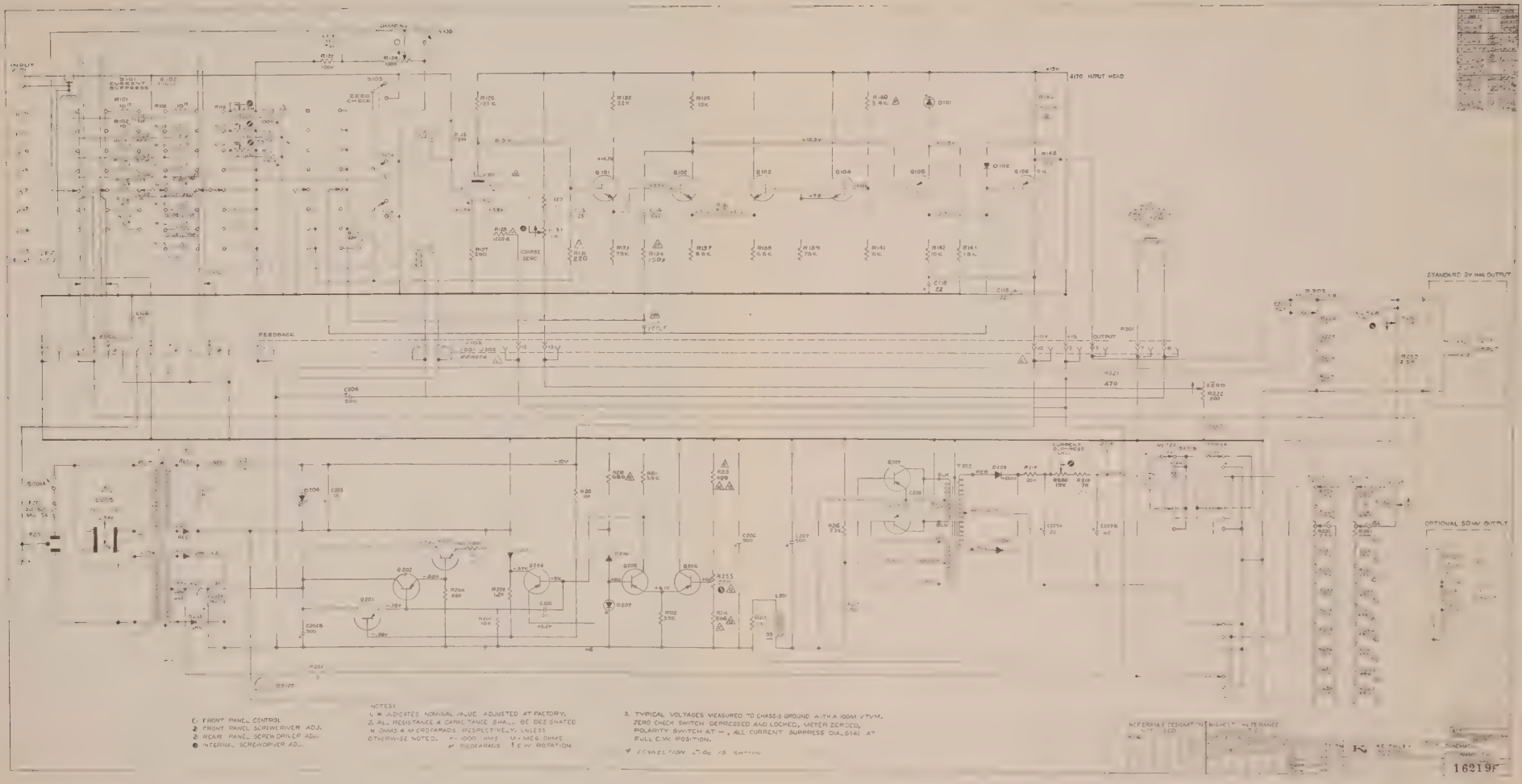
△ T102 IS SHOWN INSERTED IN J201.

REFER TO ELECTRICAL SPECIFICATIONS

KEITHLEY INSTRUMENTS

SCHEMATIC, 4160
4160 PICOAMMETER
PART 1 REV

16556F


INPUT
S101 CURRENT SUPPRESS
S103 ZERO CHECK
4170 INPUT HEAD
+15V
-10V
FEEDBACK
OUTPUT
STANDARD 5V MAX OUTPUT
OPTIONAL 50MV OUTPUT
CURRENT SUPPRESS
METER SHUNTS
NOTES:
1. * INDICATES NOMINAL VALUE ADJUSTED AT FACTORY.
2. ALL RESISTANCE & CAPACITANCE SHALL BE DESIGNATED IN OHMS & MICROFARADS RESPECTIVELY, UNLESS OTHERWISE NOTED. K = 1000 OHMS M = MEG OHMS
MF = MICROFARADS ↑ C.W. ROTATION
3. TYPICAL VOLTAGES MEASURED TO CHASSIS GROUND WITH A 100M VTVM, ZERO CHECK SWITCH DEPRESSED AND LOCKED, METER ZEROED, POLARITY SWITCH AT —, ALL CURRENT SUPPRESS DIALS(14) AT FULL C.W. POSITION.
* EQUALIZATION .3 OR 1.5 SHUNT
C FRONT PANEL CONTROL
2 FRONT PANEL SCREWDRIVER ADJ.
3 REAR PANEL SCREWDRIVER ADJ.
INTERNAL SCREWDRIVER ADJ.
REFERENCE DESIGNATION
NOT USED
HIGHEST REFERENCE
16219F

KEITHLEY INSTRUMENTS, INC.
REPAIR & CALIBRATION FORM

MODEL NO. _____
SERIAL NO. _____

DATE _____

R-

SHIP INSTRUMENT & FORM TO:

SALES SERVICE DEPT.
KEITHLEY INSTRUMENTS, INC.
28775 AURORA ROAD
CLEVELAND, OHIO 44139

FROM:

USER'S NAME _____
RETURN ADDRESS _____
_____
CITY _____
STATE _____ ZIP _____
TELEPHONE _____

1. REASON FOR RETURN. Check appropriate box.
   - ☐ Repair and Recalibration
   - ☐ Recalibration only. (If repairs are required to meet specifications, an additional repair charge will be added to recalibration cost.)

2. CALIBRATION REPORT. Specify report desired. (See reverse side of form for details.)
   - ☐ Calibration Report (Certified Traceable to N.B.S.)
   - ☐ Calibration Report (Production Calibration Equipment at the factory)
   - ☐ Certificate of Compliance

3. DESCRIPTION OF PROBLEM. (Include a block diagram of instruments connected in system. Recorder charts or other data would be helpful.)

_____

_____

_____

_____

Is problem constant or intermittent? _____

4. OPERATING CONDITIONS.
   Control setting (range, multiplier, etc.) _____
   Line voltage used _____ Line frequency used _____
   Temperature _____ °F Temperature variation ± _____ °F
   Humidity (high, medium, low) _____
   Other (please specify, such as line transients, etc.) _____

5. EQUIPMENT USED.
   Signal source _____ Source impedance _____
   Readout device _____ (Recorder, oscilloscope, etc.)
   Cables used _____ Length _____

6. ADDITIONAL INFORMATION. Please indicate any other pertinent information which may help the Keithley Repair and Calibration Department. (If repairs or modifications have been made to instrument by other than Keithley personnel, please specify below.)

_____

_____

_____

_____ REV 0172

CALIBRATIONS AVAILABLE AT KEITHLEY INSTRUMENTS. EFFECTIVE: FEBRUARY 1, 1972

Listed and defined below are the four types of calibrations and their associated report formats which are presently available at Keithley Instruments. They fall into the following categories:

1. Report of Calibration Certified Traceable to the National Bureau of Standards
2. Calibration Report
3. Certificate of Compliance
4. Recalibration

All calibration and certification performed by Keithley Instruments is in accord with MIL-C-45662A.

Prices shown below are in addition to repair charges for any work necessary to place a customer's unit into first class condition prior to the calibration.

1. Report of Calibration Certified Traceable to the National Bureau of Standards.
This is a completely documented report, including all basic errors or deviations from nominal settings on appropriate ranges, terminals, dials, etc. Work is performed using the primary standards of the company with secondary transfers kept to a minimum. The NBS test numbers for the latest recalibration of the primary standards are furnished.

By definition, the above is performed in our Standards Laboratory so that random operator induced error is minimized and maximum protection to the equipment used is maintained.

This type of calibration is not recommended for instruments with a basic inaccuracy of 1% or greater. The precision involved in this report makes it uneconomical for such instruments. The Calibration Report listed below (No. 2) would be better suited in this case.

The Report of Calibration Certified Traceable to the National Bureau of Standards is available on the following instruments at the prices listed:

Model 140	$275	Model 5155-10^{8}	$ 50
Model 260	$225	Model 5155-10^{9}	$ 50
Model 261	$375	Model 5155-10^{10}	$ 50
Model 662	$275	Model 5155-10^{11}	$ 60
Model 5155 (Complete Set)	$295	Model 5155-10^{12}	$ 60
		Model 5155-10^{13}	$ 80

2. Calibration Report.
This report shows only the cardinal range, terminal, dial, etc. errors as determined by production calibration equipment and personnel. The production equipment is maintained traceable by transfer techniques against the primary standards maintained by the company. We attest to this fact and list basic deviations from nominal but the conditions of calibration are not as precisely controlled as the previous report nor are NBS test numbers supplied.

This report is available for any instrument in our line. The following price has been established for this report:

Model 261 . . . . . $ 60
Prices for other units can be estimated upon request.

3. Certificate of Compliance.
This is merely a restatement of the basic guarantee that the instrument was calibrated on equipment that is maintained by our standards personnel against primary standards. No report is issued.

This Certificate of Compliance is available at no charge for any instrument with the exception of the Model 261.

A newly purchased Model 261 or one returned for repair or recalibration is automatically supplied with a Calibration Report (as described in (2) above). The nature of this instrument makes it necessary to complete this report to ascertain specified accuracy. This Calibration Report is forwarded to the customer with the instrument. The $60 charge is incorporated as part of the normal calibration charge of the Model 261.

4. Recalibration.
This is a recalibration of the instrument according to our factory calibration procedures.

Model 260 . . . . . $ 90 (No report supplied. A Certificate of Compliance can be had at no charge if requested).

Model 261 . . . . . $ 60 (Calibration Report as described in (2) above is supplied. See (3) for explanation).

All other instruments are on a time and material basis for the particular unit involved.

All prices subject to change without prior notification.

KEITHLEY INSTRUMENTS, INC.
MODELS 416, 417
HIGH SPEED PICOAMMETERS

Operation:

Page 11: Change Table 2 as follows:

Output Voltage	R_A Value	Keithley Part No.	R_A Value	Keithley Part No.
1 volt	2 KΩ	R61-2K	1 KΩ	R135-11C
100 mv	2.9 KΩ	R127-2.9K	100 Ω	R127-100
50 mv	2.95 KΩ	R127-2.95K	50 Ω	R127-50
10 mv	2.99 KΩ	R127-2.99K	10 Ω	R127-10

TABLE 2. Resistor values for desired recorder output. Resistor R127 is a metal-film type, 1/2 w, 0.25%. Resistor R135 is 1/2w, 0.1%.

KEITHLEY INSTRUMENTS, INC.

28775 AURORA ROAD • CLEVELAND, OHIO 44139 • (216) 248-0400
TELEX: 98-5469 • CABLE: KEITHLEY